PROGRESS REPORT 161

PENNSYLVANIA GEOLOGICAL SURVEY

Fourth Series

THE PRECAMBRIAN GEOLOGY OF THE READING 15′ QUADRANGLE

by

Tracy V. Buckwalter

COMMONWEALTH OF PENNSYLVANIA

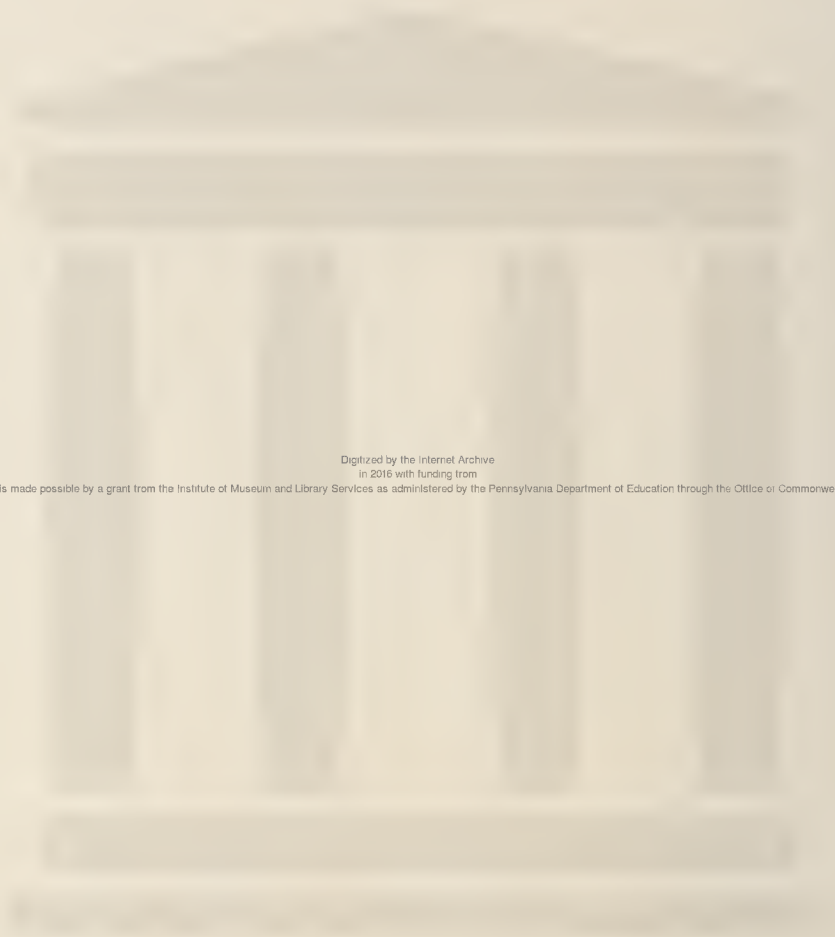
DEPARTMENT OF INTERNAL AFFAIRS

GENEVIEVE BLATT, *Secretary*

TOPOGRAPHIC AND GEOLOGIC SURVEY

ARTHUR A. SOCOLOW, *State Geologist*

1962



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CONTENTS

	Page
ABSTRACT	1
INTRODUCTION	2
Scope of Report	2
Location, Topography, and Drainage	2
Field Work and Acknowledgements	3
Previous Work	3
PRECAMBRIAN ROCKS	4
General Statement	4
Graphitic Gneiss	5
Distribution	5
Petrography	5
Origin	7
Quartz-Biotite-Feldspar Gneiss	7
Hornblende Gneiss	8
Distribution and Occurrence	8
Petrography	9
Origin	10
Correlation	11
Granitic Gneiss	12
Distribution and Occurrence	12
Petrography	12
Correlation	14
Origin	15
Pegmatite	19
Quartz Diorite Gneiss	20
Distribution and Name	20
Petrography	21
Field Relations and Origin	21
Metadiabase	22
Distribution and Occurrence	22
Petrography	22
Age	23
PALEOZOIC ROCKS	24
Hardyston Formation	24
Distribution	24
Stratigraphy and Petrography	24
Thickness	27

Measured Sections ---------- 28
Cambro-Ordovician Carbonate Rocks ---------- 33

STRUCTURE ---------- 34

Precambrian Structure ---------- 34
Paleozoic Structure ---------- 35
Overthrust Interpretation ---------- 35
Hardyston Ridges ---------- 38
Neversink Mountain ---------- 43

REFERENCES CITED ---------- 45

ILLUSTRATIONS

Plate

GEOLOGIC MAP OF THE PRECAMBRIAN ROCKS AND HARDYSTON FORMATION ---------- 1

THIRTEEN FIGURES DEALING WITH PALEOZOIC AND PRECAMBRIAN STRUCTURES ---------- 2

GEOLOGY OF THE PRECAMBRIAN ROCKS AND HARDYSTON FORMATION OF THE READING QUADRANGLE, BERKS COUNTY, PENNSYLVANIA

by

Tracy V. Buckwalter

ABSTRACT

This progress report deals with the areal geology, petrography, structure and origin of the Precambrian crystalline rocks and the Lower Cambrian Hardyston Formation of that portion of the Reading Highlands within the 15-minute Reading Quadrangle.

The oldest crystalline rocks include the metasedimentary graphitic gneiss, quartz-biotite-feldspar gneiss, and hornblende gneiss, which is at least partly of metasedimentary origin. Widespread granitic gneiss has formed partly by replacement of hornblende gneiss, but some is probably igneous. Abundant migmatites, including quartz diorite gneiss, have been formed by invasion of the older gneisses by granitic and pegmatitic material, much of it by lit-par-lit injection. Metadiabase cuts all the crystalline rocks.

The Hardyston Formation, estimated to be 600 feet thick, consists in ascending order of a basal conglomerate, a group of transitional conglomeratic quartzites, orthoquartzites and feldspathic sandstones, and, rarely, jasper. A phyllitic rock, termed pinite, occurring below the conglomerate, and included by some within the Hardyston, is believed to have been formed by cataclastic metamorphism of granitic gneiss. The source area of the Hardyston lies east of the quadrangle, as suggested by increasing feldspar content of the lower conglomerate.

The foliation of the Precambrian rocks strikes northeast in the southern part of the quadrangle and trends northeast to east in the northern part. The dip of the foliation is generally to the southeast. Details of Precambrian structure are largely lacking.

It is concluded that the major part of the uplift is rooted in place and not part of a great overthrust sheet. A long east-west belt of overthrust hills, including Neversink Mountain, is present in the southern part of the Reading Hills in this quadrangle. The structural interpretation of the numerous long Hardyston ridges which occur within and which flank the crystallines is discussed. The view that they are largely strongly sheared overturned synclines is favored. Details of the structure of Neversink Mountain are presented.

INTRODUCTION

SCOPE OF REPORT

This report describes the progress to October, 1962, of a geologi survey of the crystalline rocks and Hardyston Formation in the Reading 15 minute quadrangle of Berks County, Pennsylvania. This survey is part of a larger program which will eventually result in a comprehensive report on the geology of the entire quadrangle. The present report includes a geologic map and cross sections of the area, and megascopic and petrographic descriptions and interpretations of the formations encountered.

LOCATION, TOPOGRAPHY, AND DRAINAGE

The area mapped lies within the Reading 15-minute quadrangle which includes the following 7 1/2-minute quadrangles: Fleetwood on the northeast, Birdsboro on the southeast, Temple on the northwest, and Reading on the southwest. All are within Berks County in southeastern Pennsylvania. Reading, the only city in the area, is located in the central part of the Reading 7 1/2-minute quadrangle.

The rocks mapped consist of Precambrian crystalline rocks and minor lowest Paleozoic rocks. They constitute the western part of a belt hills and ridges called by various workers the Reading Hills, Reading-Boyertown Hills, Durham and Reading Hills, South Mountain, and the Reading Prong of the New England Upland. This highland is continuous to the east with the highlands of New Jersey, southeastern New York, and western New England. It is bordered on the north and west by Cambr Ordovician carbonate rocks and shales of the Great Valley and to the south by red sediments and intrusives of the Triassic Lowland. The great bulk of the highlands terminates at Reading. However narrow outliers, including the hills just south of Shillington in the Reading 7 -/2-minute quad rangle, extend westward 15 miles to South Mountain in Lebanon County.

The highest elevation in the quadrangle is on Mt. Penn, 1120 feet just east of the city of Reading. Many of the gneissic hills and quartzite ridges attain elevations of 900 to 1000 feet. Striking topographic features of the Reading Hills are the flat-bottomed, long, relatively narrow intermontane valleys which penetrate into the hills from the borders or, as in the Boyertown quadrangle to the east, are completely enclosed within the hills. Some of these valleys are demonstrably floored by carbonate rocks others are devoid of any outcrops. In the Reading quadrangle, limestone-floored valleys are represented by the valley extending from the Borough of Mt. Penn to Stony Creek Mills and by the western part of Oley Valley, the largest of all. The floor of these valleys ranges from about 300 to 400 feet in elevation. The structural meaning of these valleys has been a subject of much controversy as mentioned in the section on structural geology.

The drainage of the entire area goes to the Schuylkill River. The chief tributaries are Willow Creek to the north, Laurel and Bernhart Creeks to the west, and Antietam, Monocacy and Bieber Creeks to the south. A few of the valleys cutting into the hills are over 300 feet deep; the relief from Bernhart Creek to Deer Path Hill which forms part of its south side is over 600 feet.

FIELD WORK AND ACKNOWLEDGEMENTS

Most of the field work in this quadrangle was done during parts or all of the summers of 1956, 1957, 1958, and 1960. All the mapping was done by foot traverses and first recorded on aerial photographs of 1:20,000 scale. The base maps used were the U.S. Geological Survey advance sheets of Fleetwood, Temple, and Reading quadrangles and the final U.S.G.S. map of Birdsboro quadrangle. All are to a scale of 1:24,000. About 100 thin sections were made from about 200 samples collected from the various rock types.

The writer gratefully acknowledges the numerous suggestions and aid of Carlyle Gray, former State Geologist, Alan Geyer, Assistant State Geologist, Arthur Socolow, State Geologist, Vincent Shepps, and others of the Pennsylvania Geological Survey. Hans Wilkens of Reading gave freely of his knowledge, particularly of the Hardyston occurrences, as he has with earlier workers. Seven graduate students at the University of Pittsburgh aided in petrographic and limited field studies of various formations. Wendelin Frantz, Murray Dougherty, Robert Barsdate, Orloff Lake, and Henry Salver all worked on various aspects of the lithologic variation of the Hardyston Formation in both the Reading and Boyertown quadrangles. Frederick Park's Master of Science thesis dealt with the petrography of the crystalline rocks and their possible correlations with those of northern New Jersey. Donald Groff made a spectographic analysis of several arkoses and feldspathic sandstones of the Hardyston Formation as part of a larger study of the geochemistry of sandstones. Many local residents, too numerous to mention by name, are to be thanked for their aid. Finally, the use of the facilities for petrographic work at the Department of Geology at the University of Pittsburgh is gratefully acknowledged.

PREVIOUS WORK

The earliest report specifically covering some of the Reading Hills was that by H. D. Rogers in 1858. An interesting cross section of Neversink Mountain is shown therein (p. 103). In the early 1880's the Second Pennsylvania Survey mapped the entire state on at least a reconnaissance scale and locally in detail. E. V. D'Invilliers (1883) wrote the portion dealing with the "South Mountains or Reading Hills of Berks County." A. C. Spencer of the U.S. Geological Survey in 1908 mapped

the southern edge of the hills in parts of the Reading and Birdsboro quadrangles in the course of a study of the magnetite deposits there. Harry N. Eaton in 1912 mapped the Reading Hills in reconnaissance from South Mountain in Lebanon County eastward through the Reading quadrangle into the southern part of the Boyertown quadrangle. Edgar T. Wherry mapped the Paleozoic and Triassic rocks of the Reading, Boyertown, Quakertown, and Doylestown quadrangles, including some of those in the present report from 1909 to 1914. Eleanora Bliss and Anna Jonas mapped the Precambrian rocks of the Reading, Boyertown, Slatington, and Quakertown quadrangles in 1912-14. However, neither their maps nor Wherry's maps on the Reading quadrangle were published in their entirety as quadrangle maps. Wherry's study (1909) of the Triassic sill and flow near Jacksonwald in the Birdsboro quadrangle was published separately as were some of his studies (1918) on the crystalline rocks of eastern Pennsylvania, including part of the Reading Hills. Stose and Jonas (1935, 1939, 1940) published a controversial structural interpretation of the Reading Hills, which was strongly opposed in several papers by Miller and Fraser (1936; Fraser, 1938, 1939, 1941, Miller, 1944). Wilkens (1955, 1957, 1957a) made brief studies of the Harydston quartzite, erosional surfaces, and terrace deposits around Reading. The writer has worked on the crystallines and the Harydston in the adjoining Womelsdorf (in press) and Sinking Spring quadrangles to the west and Boyertown quadrangle (1953, 1956, 1959) to the east and commented on the structure indicated by the Hardyston in the Reading quadrangle (1960) and on aspects of granitization at Antietam Lake (1958).

PRECAMBRIAN ROCKS

GENERAL STATEMENT

The Precambrian rocks of Pennsylvania may be divided into three geographic and petrographic groups--those of the Piedmont Province in the southeastern corner of the state near Philadelphia; those of South Mountain near Carlisle, which are the northernmost part of the Blue Ridge Province; and those of the Reading Prong, which continues eastward into northern New Jersey, southeastern New York, and western New England. The crystalline rocks of the Reading Prong bear more resemblance to those of the Highlands of New Jersey than to those of the Piedmont which are separated geographically only by the Triassic lowland. Because of the essential identity of the rocks of the Reading quadrangle with those of the Boyertown quadrangle to the east and Womelsdorf to the west, some of the writer's earlier descriptions (1953, 1956, 1959) have been utilized in modified form.

The formations recognized in the Reading quadrangle are listed below in approximate order of age, with the oldest at the bottom.

	Metadiabase
	Quartz diorite gneiss
	Pegmatite
	Granitic gneiss
Probably	(Hornblende gneiss
contemporaneous	(Quartz-biotite-feldspar gneiss
	(Graphitic gneiss

Graphitic gneiss, quartz-biotite-feldspar gneiss, and probably most of hornblende gneiss are metasediments. Granitic gneiss and pegmatite are believed to be in part "granitized" metasediment and in part locally igneous. Quartz diorite gneiss is probably a migmatite, and metadiabase is meta-igneous.

GRAPHITIC GNEISS

Distribution

Graphitic gneiss and associated migmatites occur in three areas in the Reading 15-minute quadrangle. Two small ones are located one-half mile southeast of Pricetown in the Fleetwood 7 1/2-minute quadrangle and at Reiffton at the west central edge of the Birdsboro 7 1/2-minute quadrangle. A considerably larger area of about one-half square mile is located immediately west of Oley Line in the north half of the Birdsboro 7 1/2-minute quadrangle. The gneiss crops out at one place in the Oley Line area; otherwise, all the exposures are float. Hornblende gneiss and migmatites, formed by injection of graphitic gneiss by granitic material, are common in the float with graphitic gneiss.

Petrography

The typical gneiss is a light-gray, occasionally pinkish to reddish gneiss with a grain size of about one-half to one millimeter. On weathered surfaces the feldspars become dull white to buff and the ferromagnesians become limonitic, so that the rock has a speckled brown and white appearance. Petrographic study of identical rocks in the adjoining Boyertown quadrangle, where this gneiss is much better exposed, indicates that quartz ranges from about 20 to 50 percent, orthoclase or microcline from about 0 to 50 percent and plagioclase, largely andesine, from about 10 to 35 percent. Microcline is widely variable in quantity. Where it occurs at all it generally comprises nearly half the rock. It appears to be commonest in the darker gneisses whereas orthoclase is commoner in the lighter colored ones. Biotite is the only common ferromagnesian mineral. It occurs in quantities from 0 to 10 percent. Rarely hypersthene or garnet comprises 5 percent of the rock; graphite comprises from 0 to 10 percent. Magnetite is the only common accessory mineral. Although graphite is quantitatively not important, where it occurs it is the most

conspicuous mineral with its glistening, tin-white flakes one to two millimeters in diameter. The gneissic structure is more evident than that of granitic gneiss but less apparent than in hornblende gneiss. It is due to a parallelism of the ferromagnesian and graphite minerals and to a slight elongation of quartz and feldspar crystals.

The most abundant variety of graphitic gneiss in the Reading quadrangle is a coarser grained (1/2 to 6 mm) migmatite resulting from the injection of the fine-grained graphitic gneiss (mentioned above) by granitic material. As would be expected, this migmatite is considerably richer in quartz and potash feldspar than the uninjected graphitic gneiss. Quartz ranges commonly from 30 to 60 percent, and potash feldspar, both orthoclase and microcline, from about 35 to 80 percent. The extra potash feldspar has apparently come from intrusion by the granitic and pegmatitic solutions which formed almost certainly at a higher temperature than the graphitic gneiss itself. The work of Tuttle and Bowen (1958) suggests that such solutions can form as low as about 600°C. This is probably at least 100° to 200° higher than the temperature of formation of graphite at its facies of regional metamorphism. Granitic seams and veins are abundantly intruded parallel to the gneissic structure. Locally, injection and "soaking" by granitic material have been so intense that little is left megascopically to indicate graphitic gneiss except a little graphite. The following criteria, published in an earlier report by the writer (1959), and reproduced here again for convenience help to distinguish graphitic gneisses from granitic gneiss:

Graphitic gneiss	Granitic gneiss
1. Usually low in ferromagnesians except biotite	1. Usually some ferromagnesians, particularly hornblende
2. Usually strong elongation of quartz and feldspar	2. Generally weak quartz-feldspar elongation
3. Usually very fine-grained (1/2 mm and less)	3. Usually medium to coarse grained (1 to 5 mm)
4. Some float pieces weather fairly soft. Broken without difficulty	4. Mostly hard resistant float
5. Usually weathers light buff	5. Weathers buff or gray
6. Fairly evident gneissic structure	6. Usually rather weak gneissic structure
7. Tends to weather into small slab-like pieces	7. Tends to weather into knobby, larger rounded boulders
8. Associated in places with some gneiss varieties intermediate between hornblende gneiss and typical graphitic gneiss	8. Usually associated with hornblende gneiss or gabbroic gneiss

On weathering this migmatitic gneiss shows the same blotchy brown and white appearance as the finer grained variety.

A considerably less abundant variety of graphitic gneiss is a fine-grained, medium-to dark-gray gneiss with a blue to blue-gray cast. This gneiss, while rather different mineralogically from typical graphitic gneiss, has been found also at nearly all graphitic gneiss localities in the Boyertown quadrangle and on South Mountain in the Womelsdorf quadrangle. At the latter locality it occurs as a bed about two feet thick interbedded with the more typical graphitic gneiss. It contains from 15 to 45 percent hypersthene, about 20 to 35 percent andesine or labradorite, 10 to 15 percent orthoclase and occasionally microcline and as much as 50 percent quartz. Locally a few percent of garnet, hornblende, or biotite may be present. It is thus about intermediate in composition between the pyroxene-rich variety of hornblende gneiss and typical graphitic gneiss. Graphite is sparing and the darker phases of this rock may be easily confused with either hornblende gneiss, quartz diorite gneiss or even the coarser phases of metadiabase. Float pieces frequently show a hard buff outer zone around a tough inner blue-gray core.

Origin

Graphitic gneiss very probably formed by regional metamorphism of a carbonaceous sandstone and,to judge by the mineral composition, reached the sillimanite-almandite subfacies of the amphibolite facies. Graphite is usually thought to indicate metamorphism of carbonaceous sediment (Heinrich, 1956, p.223). The occurrence of biotite as the most abundant ferromagnesian mineral,and the occasional presence of garnet, also lend support to the idea of sedimentary origin. Microscopically graphitic gneiss shows no indications of former igneous textures. A graphitic gneiss from the Boyertown quadrangle contains two varieties of plagioclase which may be explained almost certainly only by a sedimentary origin. Near the town of Boyertown, some fair quarry exposures and abundant float strongly suggest that graphitic gneiss, almost identical to that of the Reading quadrangle, is interbedded with marble, there called the Franklin limestone. As the marble is certainly of metasedimentary origin, the interbedded graphitic gneiss would also then be metasedimentary. Quartz-graphite-feldspar gneisses of Lehigh and Northampton Counties (Fraser, 1941, p. 144-146), which are much like graphitic gneiss are also intimately associated with marble. Correlation of the Reading Hills graphitic gneisses with somewhat similar metasediments in northern New Jersey and in the Piedmont near Philadelphia is less certain, as Park (1961, p. 18-20) has shown.

QUARTZ-BIOTITE-FELDSPAR GNEISS

This minor gneiss occurs in only one small area at Oley Furnace in the Fleetwood 7 1/2-minute quadrangle. Although the area of exposure is only about 1500 feet long, four outcrops are present, the most conspicuous one being on the main east-west road leading from Oley Furnace

to the Pricetown-Oley highway. It is very light-gray to nearly white on the weathered surfaces, and tends to split rather readily into thin slabs parallel to the gneissic structure. It is somewhat friable on weathering, and at one pit has weathered in the upper few feet to a loose light-colored sand. Most of the grains are one to two millimeters long. The gneiss consists of about 30 percent quartz, 30 percent orthoclase, 30 percent andesine (An_{36}), 5 percent biotite and minor amounts of magnetite, zircon, clay minerals and sericite. The gneissic structure is caused by conspicuous, fairly abundant layers of biotite, usaully about a millimeter thick, and a noticeable elongation of some of the quartz and feldspar. Excepting the elongated grains, the rock exhibits a distinctly sugary texture. Feldspar weathers to clay minerals which are sometimes present between feldspar grains in the rock.

Hornblende gneiss occurs with the quartz-biotite-feldspar gneiss in float at the south edge of the area of exposure, but definite field relations, which might cast light on its origin, are not found. Because of the fine banding, the slightly friable, sugary texture, the presence of biotite as the only mafic mineral and in general an appearance totally unlike that of any of the igneous or granitized gneisses of the quadrangle, it seems probable that this gneiss is of metasedimentary origin. Some support is lent this origin by the occurrence in the Boyertown quadrangle of similar gneisses, some of which contain sillimanite, carbonate, and garnet, all more suggestive of a sedimentary origin. The large quantity of feldspar poses a problem, however, if the source is a sediment. If all the feldspar now present were inherited from the source, a very feldspathic arkose or possibly feldspathic graywacke would be a possible parent rock. There is little indication of potash metasomatism or injection by granitic fluids which might have increased an originally lower feldspar content.

HORNBLENDE GNEISS

Distribution and Occurrence

Hornblende gneiss is the second most abundant Precambrian formation, although its area of exposure is much less extensive than that of granitic gneiss. Along with its associated migmatites formed by slight to moderate injection by granitic material, it underlies about a tenth of the total areas of crystalline rocks. Larger areas of strongly to very strongly injected to nearly assimilated hornblende gneiss are mapped with granitic gneiss which they resemble more closely mineralogically. The most extensive areas of hornblende gneiss are located on the east side of Mt. Penn, north of Antietam Reservoir, and near Oley Furnace, Fleetwood and Stony Point. All of these areas are more or less elongated in a northeast-southwest direction. Mapping of these areas, however, is

ıecessarily inexact because of the scarcity of hornblende gneiss outcrops. Most of the mapping had to be done on float which was often abundant nough to indicate the underlying rocks with reasonable accuracy, but requently scarce in cultivated areas.

Petrography

Hornblende gneiss is commonly a fairly well-foliated gneiss vhich is dark-gray to black with grains about one to two millimeters in iameter. The foliation is caused by parallelism of hornblende grains nd occasionally by pyroxene grains. The ferromagnesians occur in a few laces in discontinuous bands a few centimeters long separated by bands f plagioclase, but usually banding is inconspicuous. Frequently a "salt nd pepper" texture may be seen which is caused by the presence of about n even amount of black hornblende crystals distributed among gray lagioclase grains.

Hornblende usually comprises about 50 percent of the rock, but it has een observed to range from 70 percent to a trace. Pyroxene is frequently resent in minor amounts up to about 10 percent, although rarely it is the redominant ferromagnesian mineral. Pyroxene includes the orthopyroxene, ypersthene, and a clinopyroxene, which is apparently augite. The clino- yroxene and orthopyroxene may be present together or separately. This elation was noted earlier by Sims (1958, p. 15) in the amphibolites of the)over area of northern New Jersey. Biotite is usually absent except in a ew gneisses where it comprises 10 to 15 percent of the rock. At one ocality one-half mile south of Alsace Manor, about 5 percent of red garnet s present. Quartz is rare or lacking, except in the migmatites which have een intruded by granitic material.

A little hornblende gneiss displays but slight foliation, and in arlier work by the writer (1959) was referred to as gabbroic gneiss. It s so commonly associated with the better foliated typical hornblende gneiss iat separation in the field is not practical. Mineralogically and texturally, xcept for its weak gneissic structure, it is very similar to the commoner)liated gneiss. It tends to contain a little more pyroxene than typical ornblende gneiss. All gradations have been noted between the common, etter foliated hornblende gneiss and the gabbroic gneiss.

In the common hornblende gneiss and also in the gabbroic gneiss, ornblende usually is pleochroic from light yellow brown to dark brown. ı two of the pyroxene-rich gneisses hornblende tends to be greener than ı the normal hornblende gneiss. The optic angle of hornblende in the ommon hornblende gneiss is visually estimated at 70°. The maximum)served extinction angle between the C axis and the slow ray is 24°. iotite, where it occurs, is usually pleochroic from light yellow brown) deep brown. It usually occurs as elongate crystals somewhat embayed

by feldspar and occasionally quartz. The ends of the crystals are frequently ragged and frayed. The clinopyroxene is mostly pale green augite which closely resembles diopside but has a larger extinction angle (54°). A little diallage, with prominent parting, is present. Light pink hypersthene is the orthopyroxene, frequently showing some contrast in color to the green augite. The pyroxenes are almost entirely anhedral, although a few are subhedral and elongated. They usually exhibit a mosaic texture with the other minerals. Augite is occasionally poikilitically enclosed within hornblende and a very few crystals occur as cores within hornblend suggesting that hornblende is later than pyroxene. Most of the pyroxene is anhedral and shows no obvious paragenetic relations with hornblende and the other minerals.

Origin

Unequivocal evidence of the origin of hornblende gneiss of the Reading quadrangle is lacking. However, identical hornblende gneiss in the Boyertown quadrangle immediately to the east appears in part to be of sedimentary origin (Buckwalter, 1959). There, well-foliated hornblende is interbedded with and grades into quartz-feldspar graphite gneisses of almost certain sedimentary origin. In the Boyertown quadrangle and also in South Mountain in the Womelsdorf quadrangle both hornblende gneiss and graphitic gneiss are interbedded with a dark gray hornblende pyroxene gneiss which superficially looks like a fine-grained anorthosite. This gneiss is also found intimately associated with hornblende gneiss and graphitic gneiss in float near Oley Line in the Birdsbor 7 1/2-minute quadrangle, thus lending support to the sedimentary origin o some of the hornblende gneiss of the Reading area. Interbedding of hornblende gneiss with the graphitic metasediments may suggest that hornblende gneiss represents metamorphosed sills or flows of diabase or basalt. This is improbable, however, because of the gradation zones between hornblende gneiss and the metasediments.

The origin of the weakly gneissic gabbroic hornblende gneiss is considerably more uncertain than that of the typical hornblende gneiss. Superficially, it looks somewhat like an igneous rock, but because of its gradation into typical hornblende gneiss and its nearly similar mineral composition, it is possible that it is also of sedimentary origin. Field relations are of little aid in determining its origin and indeed this gneiss is very poorly exposed. Microscopically, the crystalloblastic and mosai texture give little indication of a former igneous origin. Few of the crystals are subhedral and typical igneous textures like porphyritic, diabase, or hypidiomorphic are not evident.

The minerals of both the more typical hornblende gneiss and gabbroic gneiss suggest they have been regionally metamorphosed to the sillimanite-almandite subfacies of the amphibolite facies. At approximat

his facies the color of hornblende changes from green to brown (Miyashiro, 1961), as it is in most of these gneisses. Amphibolites similar to these and at about the same stage of metamorphism have been described by Sims (1958, p. 15, 25) in the Dover area of northern New Jersey. For somewhat similar reasons they have been considered to be of questionable metasedimentary origin.

The parent rocks of some metamorphic rocks that have not undergone metasomation can sometimes be determined by comparison of the bulk composition of the metamorphic rock with the composition of various possible source rocks. With rocks of simple mineral composition the chemical composition may be fairly readily calculated from the optical properties. This sort of calculation is not very feasible for hornblende gneiss because of the difficulty of correlating the optical properties of hornblende with its complex chemical composition. Friedman (1960, p. 73) has commented on the problems of these calculations, including those of amphiboles. Finally, determination of the parent rock of hornblende gneiss by comparison of its chemical composition with possible parent rocks is rendered difficult because a variety of rocks with similar composition but different origins may ultimately give rise to hornblende gneiss as a result of regional metamorphism. Thus, some tuffs, basalts, gabbros, and certain calcareous, ferruginous sediments, like limey shales, all may converge on metamorphism to give rise to hornblende gneiss.

Correlation

Correlation of crystalline rocks between geographically separated areas is uncertain at best even where the areas are relatively close. Under favorable conditions correlation of a crystalline rock formation can be approximated by four means, namely, similar field relations to other rocks, similarity of mineral composition and texture, continuity of exposure, and similar ages obtained by geochronological methods. No age dates are available yet for the crystallines of the Reading Hills, but the other three methods are of some aid in attempting to correlate the Reading Hills crystallines with the crystallines of South Mountain, about 15 miles west and those farther east in the Reading Hills in Lehigh and Northampton Counties and in the Highlands of New Jersey.

Hornblende gneiss apparently correlates fairly well with amphibolitic rocks in other parts of the Reading Hills in Pennsylvania and New Jersey. In nearby parts of the Reading Hills at South Mountain in the Womelsdorf quadrangle and in the Boyertown quadrangle, the mineral composition of hornblende gneiss and the field relations are identical to those in the Reading quadrangle. Likewise the description of the petrography and field relations by Fraser (1939, p. 179; 1941, p. 149) of the Pochuck gneiss of Lehigh and Northampton Counties apply very closely to

the hornblende gneiss of the Reading quadrangle. Fraser states (1941, p. 150) that he "uses the name Pochuck for the dark-colored gneisses containing hornblende, pyroxene, and (or) biotite as dark constituents and oligoclase-andesine or andesine-labradortie as the more common plagioclase minerals." The rocks thus correspond mineralogically quite closely to the typical hornblende gneiss and the gabbroic gneiss. Finally the mineralogy and field relations of the hornblende-pyroxene amphibolites in the Dover, Franklin-Sterling, and Ringwood areas of northern New Jersey agree quite closely with hornblende gneiss of the Reading quadrangle (Park, 1961, p. 26).

GRANITIC GNEISS

Distribution and Occurrence

Granitic gneiss and its associated migmatites, which are largely of granitic composition, comprise about 75 percent of the crystalline rocks of the Reading 15-minute quadrangle. They are by far the most abundant of the Precambrian rocks. About 48 outcrops were found in the quadrangl many of them in small abandoned quarries, road cuts or excavations. Most of the granitic gneiss was necessarily mapped from float. On some wooded hills, like Chapel (Capella) Hill, three miles southwest of Pricetown, the float consists of abundant boulders and is reliable for mapping, but in many fields and cultivated areas, it is scarce and a less reliable indicator of the underlying rock.

Petrography

Typical granitic gneiss is all light-colored, much of it being light gray, some tan or bronze, and where microcline is abundant it is pink. The grain size is usually about one millimeter, although in some varieties grading into pegmatites the grains are as much as one centimeter in diameter. Gneissic structure in typical granitic gneiss is not well-defined and even lacking, but it is fairly conspicuous in most of the migmatites. It is usually caused by imperfect parallel orientation of horr blende, biotite, or chlorite and frequently by slight elongation of quartz and feldspar. It weathers in some localities to large slabs parallel to the weak gneissic structure. Locally some granitic gneiss weathers to large roughly spheroidal boulders.

The mineral composition is somewhat variable, which, as explained later, probably is caused by the replacement origin of at least some of the rock. The following table shows the ranges of the major minerals determined at the time of writing, some of the most frequent percentages and remarks relating to abundance.

Mineral	Ranges	Remarks
Quartz	8 - 43	Usually 20-30 percent
Orthoclase	0 - 33	Present in about half of localities sampled
Microcline	1 - 90	Widely variable
Perthite	0 - 60	Present in about half of localities sampled Usually 20-70 percent
Plagioclase (An_{25-42})	0 - 25	Usually 5-25 percent Present in about half of localities sampled
Hornblende	0 - 14	Ferromagnesians nearly lacking in some granites
Biotite	0 - 1	
Magnetite	0 - 3	

artz and microcline, including microcline perthite, are invariably sent. Microcline and microcline perthite compose about 20 to 60 per- t of the rock. Much of the microcline, especially that near Angstadt l on the east edge of the Fleetwood quadrangle, is pink. Perthite is quently the "string" type, though in some places it is "patch" and aid". Most of it is microcline perthite. Plagioclase is generally oclase, though sodic andesine has been found. Most, but distinctly all of the plagioclase is twinned; albite and pericline twins were the y types observed. Sericitization of all feldspars is fairly common, some places being so intense that identification is nearly impossible. some localities alteration of feldspar to clay minerals is intense. At old pit at McKnight's Gap, for example, one mile northeast of Reading, ration of all feldspars to clay is complete at a depth of 40 feet below surface. Ferromagnesian minerals of any sort are usually sparing he "typical" gneiss but become more abundant in the migmatites, es- ially those formed by injection of hornblende gneiss. Hornblende is only ferromagnesian mineral which is found with any reasonable quency, though it usually constitutes only one or two percent of the k. It is pleochroic from medium green to dark green, the darker en variety sometimes showing a brownish cast. It is considerably less ndant than the seven percent of hornblende in the approximately ivalent "Byram" hornblende granite gneiss of northern New Jersey, cribed by Sims (1958, p. 32), Hague (Hague and others, 1956, p. 451), others. Light-brown biotite occurred at only two localities. Much nblende and biotite are altered partly or wholly to fine-grained aggre- s of light-green to bright-green chlorite and locally epidote. Both erals frequently occur as ragged,corroded grains embayed by quartz potash feldspar. As the ferromagnesian minerals usually occur in ll amounts, much of the granitic gneiss may be appropriately termed ucogranitic gneiss. Accessory minerals include zircon, apatite, and enite.

Although the gneissic structure in the typical granite gneiss is weak, most of it has undergone at least moderate regional metamorphism (see section on origin). This is inferred from numerous sutured contacts between grains, especially quartz, microscopic crushed zones which have been partly recrystallized, mortar structure, and by frequent rather weak elongation of quartz and feldspar. Hornblende, and occasionally biotite, show some parallelism. However, some granite shows nearly normal interlocking "hypidiomorphic" igneous structure. Much of the granitic gneisses indicated on the accompanying geologic map consist of migmatites formed by injection and partial assimilation, in varying degrees, of hornblende gneiss by granitic material and related pegmatites. All migmatitic gradations may be found from hornblende gneiss to granitic gneiss. In mapping, these gradations were divided into four arbitrary groups which are explained in the legend on the geologic map. At some places, such as Antietam Reservoir, hornblende gneiss occurs as well-defined xenoliths in granitic gneiss and pegmatite. More commonly it is indicated by diffuse patches of hornblende crystals in granitic gneiss, by schlieren which may trail away from partly replaced xenoliths, or by considerably higher concentrations of hornblende crystals than are found in typical granitic gneiss. Some of the darker migmatites contain as much as 20 to 30 percent hornblende.

The most abundant of these migmatites is medium gray and notably darker than typical granitic gneiss. Unlike granitic gneiss, pink or bronze colors are uncommon. The grains are usually one to two millimeters long, except in pegmatitic phases where crystals are as large as one centimeter. The minerals of the migmatite are almost the same as in granitic gneiss, except that a little pyroxene and biotite from the hornblende gneiss occasionally occurs. Plagioclase, chiefly basic oligoclase and hornblende are more abundant. The gneissic structure is usually much more conspicuous than in granitic gneiss. It is caused by thin, dark discontinuous bands and lenses of hornblende and other minor ferromagnesian minerals, separated by light bands of quartz and feldspar. Many of the lenses are three to four inches long and about one-quarter inch apart, but the size and spacing vary widely. Some are difficult to distinguish because of the occurrence of separate ferromagnesian grains between the lenses and because of chloritization of these same minerals which tends to lighten the color of the bands and reduce the sharpness of their outline. This migmatite frequently weathers slightly reddish due to formation of hematitic stains. It is found abundantly in the float in large angular to slightly rounded boulders.

Correlation

Despite a gap of six miles in outcrops, correlation of granitic gneiss between the Reading Hills of Berks County and South Mountain (which is the farthest western part of the Reading Prong) is almost certain

ecause the rocks are almost identical petrographically and the field re-
ıtions with the other crystallines are the same. To the east in Lehigh
nd Northampton Counties, correlation is less certain, not only because
f the greater distance, but also because the granitic gneiss rocks there,
ıe Byram gneiss, described by Fraser (1941. p. 155), include a wider
ariety of rocks. Thus the quartz diorite gneiss and granitic gneiss mig-
ıatites of this report are all included there within the Byram gneiss.
raser evidently considered it equivalent to the Byram gneiss of northern
ew Jersey described originally by Spencer (1908, p. 5). The typical
yram gneiss, however, which he describes is very similar to the granitic
ıeiss of the Reading quadrangle, and the field relations with the other
·ystallines also appear the same, both by comparison with the published
:ports and by reviewing the rocks in the field. Within the last few years
three areas in northern New Jersey the light-colored acidic rocks have
:en considerably subdivided in the course of detailed field mapping. On
e basis of similar mineralogy and field relations the granitic gneiss of
e Reading Hills may correlate with the hornblende granite described
· Sims (1958, p. 32) in the Dover area and Hotz (1953, p. 178) at Ring-
)od. The hornblende content of the Reading granitic gneiss is lower,
.t the large amounts of microcline or microcline perthite and moderate
ıounts of relatively sodic plagioclase are similar. The granitic gneiss
es not resemble, in general, the quartz-sodic plagioclase gneisses of
rthern New Jersey such as the Losee gneiss (Hague and others, 1956,
448), the albite-oligoclase granite of the Dover area (Sims, 1958, p.
3), or the oligoclase gneiss described by Hague (Hague and others, 1956,
449) in the Franklin-Sterling area. Because of the distance of about
8 miles from Reading to the New Jersey areas, the lack of detailed in-
:mation on a portion of the intervening area, and the rather poor expo-
sres in the Reading Hills, the suggested correlations are distinctly
tıtative.

Origin

At one locality at Antietam Lake, about three miles northeast of Reading good exposures of granitic gneiss strongly suggest that the gneiss here has "granitized" or replaced hornblende gneiss. These exposures were described by the writer in an earlier paper (1960). The chief evidence which indicates that granitic gneiss has replaced hornblende gneiss is the presence of numerous xenoliths of hornblende gneiss contained within granitic gneiss, all of which are almost similarly oriented with respect to each other and the nearby hornblende gneiss country rock. Figures 1 and 2 taken from the above-mentioned paper show the relations of the xenoliths to the granitic gneiss and to the country rock. The xenoliths are interpreted as remnants of the country rock unreplaced by granitic gneiss. If the granite had been a completely fluid magma, it appears impossible that the xenoliths would have preserved orientations similar to that of the country rock. It is improbable that the xenoliths

are roof pendants because of their small size and elongate lens-like to band-like shape. Some appear to be almost certainly completely isolated in the granite gneiss. Two varieties of plagioclase rather than the one usually expected in a bonafide igneous rock provide further evidence of a replacement origin. One is oligoclase-andesine, approximately An_{30}, and the other sodic oligoclase, approximately An_{15}. Much of the plagioclase is somewhat sericitized. Hornblende of the host rock is corroded by quartz and potash feldspar and altered to chlorite, as would be expected when a basic rock is replaced by acidic material.

The Antietam Lake locality is the only one in the Reading quadrangle where xenolithic masses of hornblende gneiss crop out, but at several places where large float pieces occur, somewhat similar relations are found. Three-fourths miles southwest of Basket for example, boulders of granite gneiss several feet across contain numerous partly replaced lens-like bands of hornblende gneiss. Likewise, in the adjoining Boyertown quadrangle, similar relations prevail in a granite gneiss quarry at the west edge of Bechtelsville. Here long thin bands of hornblende gneiss, about two to ten feet apart and extending across the face of the quarry, retain approximately the same orientation in the mass of granite gneiss.

The following table gives the results of a qualitative spectrochemical analysis of three rocks from Antietam Lake; sample B which is from a hornblende gneiss xenolith, sample C from the border between a hornblende gneiss xenolith and the surrounding granitic gneiss, and sample A from the granitic gneiss. Sample C consisted of about half xenolithic material and half granitic replacing rock. The contact between the two rocks was sharply defined.

	Sample B	Sample C	Sample A		
SiO_2	45.40	63.70	74.80		
Al_2O_3	15.10	14.80	13.10		
MgO	7.90	4.20	.10		
TiO_2	1.62	.54	.11		
CaO	9.30	3.13	.28		
Na_2O	2.50	4.35	3.40		
K_2O	2.00	1.13	5.50		
H_2O	2.37	1.25	.58		
FeO	9.75	4.76	1.03		
Fe_2O_3	3.35	1.42	.32	Changes in	
CO_2	.33	.33	.33	composition**	
MnO	.15	.08	.01	B-C	B-A
PbO	.001	.001	.001	------	------
SnO_2	.001	* .001	* .001	------	------
BeO	.002	.001	* .001	-10	-10
MoO_3	.01	.001	* .001	-90	-90

V_2O_5	.01	.006	* .001	-40	-90
CuO	.01	.008	.008	-20	-20
ZnO	.001	.001	* .001	------	------
NiO	.005	.001	* .001	-40	-40
CoO	.001	.001	.001	------	------
SrO	.002	.002	.001	------	-10
Cr_2O_3	.005	.002	.002	-30	-30

*Not detected. Number indicates minimum limit of detection. Not detected: Cd, As, Te, Sb, W, Ge, Bi, Ag, Zr, Cb, B, Ba
**.001 percent equals 10ppm (parts per million)
Samples analyzed by Spectrochemical Laboratories, Inc., Pittsburgh, Pa.)

The changes in the major oxides are illustrated in the Harker diagram (Fig. 2a), in which the percentage of silica is plotted along the ordinate. The changes in trace element composition are shown in the table of compositions. As might be expected when a rock is converted from basic to acidic composition, the percentages of SiO_2, Na_2O and K_2O increase and FeO, Fe_2O_3, CaO, MgO and TiO_2 decrease. Alumina decreases slightly about as would be expected. However, Na_2O is higher in sample C, the border rock, than in the presumed final product of granitization, sample A. This is probably due to the larger amount of plagioclase in the border rock compared to the granitic gneiss, which contains more potash than plagioclase feldspar. The percentage of K_2O in the border rock, 1.13, is slightly lower than the 2.00 of the hornblende gneiss host rock. Possibly this unexpected result is due to either a small error in spectrographic determination, which is less reliable for the alkali metals, or to a slight "soaking" and introduction of K ion in the hornblende gneiss xenolith by the granitic "juices". The latter effect might not be apparent in thin section, as much of the feldspar of the hornblende gneiss is sericitized and some is indeterminate.

The quantities of some of the trace elements in hornblende gneiss are approximately those that may be expected in a paragneiss. Thus, the quantities measured by Shaw (1954, p. 1163) for Cr, 112; V, 119; Ni, 64; and Pb, 23 for the pelitic rocks of the Littletown formation of New Hampshire are of the same order of magnitude as those of Antietam Lake. Markedly different are his determinations of Cu, 18, which is five times smaller; Sr, 705, which is 35 times larger, and Ba, which usually exceeds 1,000ppm compared to the quantity at Lake Antietam which is at the limit of detection. Shaw (1954, p. 1177-1180) has noted some of the differences in trace element content between granites, shales, and diabases. He states that chromium, vanadium, and nickel are among the few elements that show distinct differences. The quantities of these elements in the hornblende gneiss xenolith are much closer to the mean of the values he gives for shales than to those for diabases, suggesting that hornblende gneiss here is of sedimentary origin. Nonetheless, the 100ppm of copper in the hornblende gneiss corresponds closer to the mean of 70 for diabase

than to the mean of about 17 for shales. Engel and Engel (1958, p. 1369) have described the chemical and mineralogical changes occurring in an Adirondack quartz-biotite-oligoclase-muscovite paragneiss during granitization. In this rock Cr, Ni, Ti, V and Sr decreased as likewise noted at Antietam Lake. Barium and lead increased whereas no change was noted at Antietam Lake. To summarize, the chemical compositions and changes between the Antietam Lake rocks on the whole are compatible with the idea of granitization of a basic paragneiss.

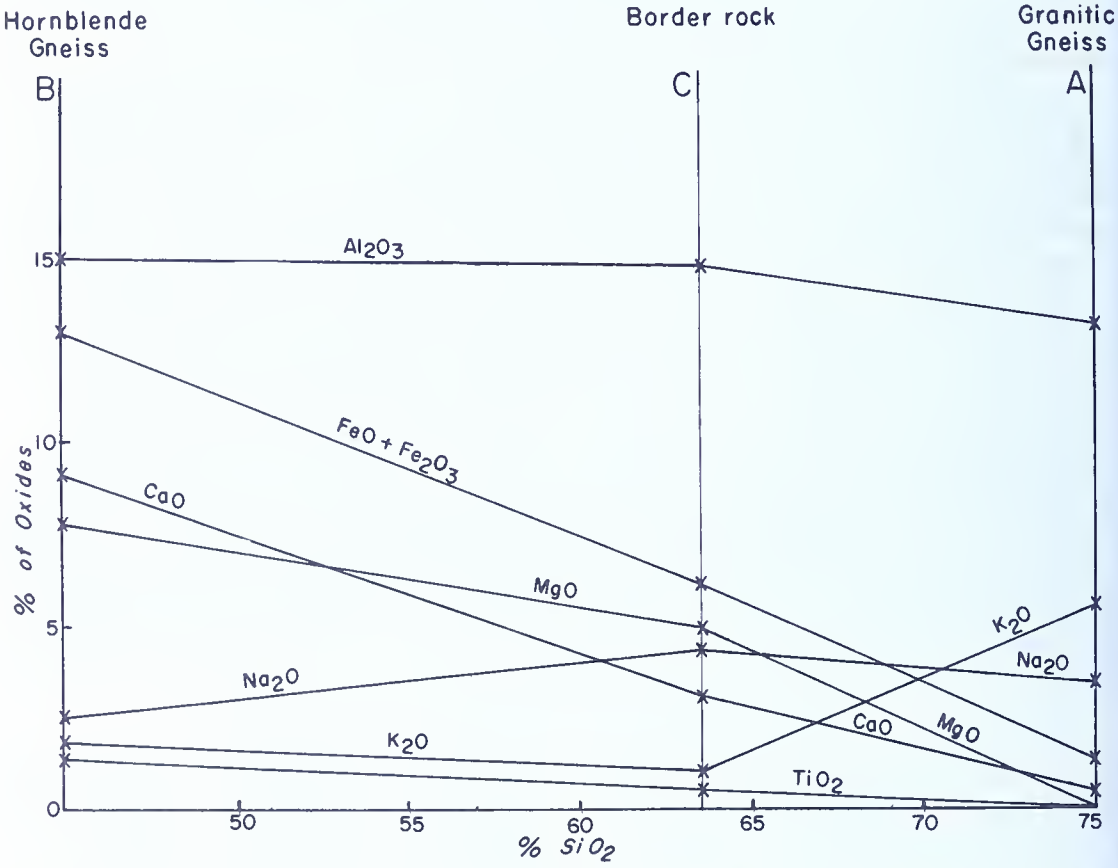

Fig. 2a Harker diagram showing changes in chemical composition of Lake Antietam rocks

A high degree of lit-par-lit injection is itself a type of granitizatio if this term is defined to mean the change of a non-granitic rock to a granitic-like rock without an intervening totally magmatic stage. Injectio of this type and "soaking" may be seen in many places in this quadrangle and elsewhere in the Reading Hills. Many of the common migmatites are clearly injected hornblende gneisses with residual bands of basic material and light bands of introduced material of granitic composition.

On the whole, however, excluding outcrops like those at Antietam Lake, field and petrographic evidence is not very convincing for a granitized origin. Many outcrops and large float boulders show no macroscopic indication of the replaced host, although they may well represent completely hornblende gneiss or possibly mobilized neo-magma, formed by selective fusion of the acidic constituents of the basic host. As noted earlier, the only types of twinning observed in plagioclase of granitic gneiss are albite and pericline. Gorai (1951), and Turner and Verhoogen (1951) have suggested that a predominance of albite and pericline twins instead of Carlsbad and more complex twins, and also the absence of twins, indicated a metamorphic rather than igneous origin for the plagioclase. Gorai further suggests that metamorphic twinning of plagioclase, in rocks like granitic gneiss, may indicate a granitized origin for the gneiss. Moorhouse (1959, p. 278-279) notes the following evidences of replacement, each weak by itself but at least locally applicable here: the presence of a more or less non-descript mosaic texture, a considerable variation in grain size within the area of a thin section, and irregularity in texture and composition.

After the formation of granite, whether by replacement or igneous means, it was regionally metamorphosed as indicated by several textural features earlier referred to, namely, numerous sutured contacts especially of quartz grains, microscopic crushed zones which have been partly recrystallized, mortar structure, weak elongation of quartz and feldspar, and slight parallelism of hornblende and minor biotite. It is probably that this metamorphism did not go much beyond the low greenschist facies and that the widespread chlorite, sericite and epidote were formed at this time in addition to the textures above. Bona fide gneissic structure, which exists in some places, may well be inherited from the original hornblende gneiss structure, rather than indicating a later high grade of metamorphism. If regional metamorphism did reach high grades, then retrograde metamorphism apparently occurred, because the chlorite, sericite, and epidote, typical of low grade metamorphic conditions, are fairly widespread.

PEGMATITE

Pegmatite and associated aplite occur widely throughout the crystallines of the Reading quadrangle, but quantitatively they are not abundant. No exposures are large enough to map separately on the scale of the map. However, in some places, such as at Bernhart Hill, near Oley Line, or Oley Furnace, pegmatite has either injected the crystalline metasediments to such an extent, or grades into or is found in granitic gneiss in such abundance, that it has been indicated on the map by addition of the letter p to the symbol of the associated crystalline. Most pegmatite occurs as dikes a few inches to a very few feet wide or as abundant seams intruding the metasediments. A good portion of the common migmatites resulting

chiefly from the invasion of hornblende gneiss by granitic gneiss are also intruded by pegmatites and some aplitic material. No pegmatites are being worked commercially in the Reading quadrangle at the time of writin nor indeed do any of the ones seen appear prospective. Although outcrops of pegmatite are uncommon so that structural relations are difficult to determine, pegmatite appears to cut all the crystallines except metadiaba Some pegmatite grades into granitic gneiss and appears to have originated from the same magmatic fluids which gave rise to the granitic gneiss as suggested earlier in the section on granitic gneiss. Although two larger pegmatite dikes on South Mountain show conspicuous zoning, none of the small masses observed in this quadrangle exhibited it.

All of the pegmatites seen in the field have a fairly simple mineral ogy corresponding to the "simple" class defined many years ago by Lande (1933). The minerals include quartz, microcline, including perthite, sod plagioclase, orthoclase, biotite, and muscovite. As is common in pegmatites, the percentages of the minerals are widely variable. However, microcline is found in all, plagioclase is less abundant, and orthoclase relatively uncommon. Some pegmatites, particularly those occurring as thin lenses in granitic gneiss, exhibit a definite gneissic structure caused by elongation of quartz and feldspar crystals. These pegmatites evidently were subjected to the same regional metamorphism as granitic gneiss (se section on granitic gneiss). The color of pegmatite ranges from white to light brown, depending on the amount of weathered ferromagnesians. The grain size, as in all pegmatites, varies widely from a few millimeters to several inches.

QUARTZ DIORITE GNEISS

Distribution and Name

Quartz diorite gneiss occurs in three areas over 200 feet in length, two being in the Fleetwood 7 1/2-minute quadrangle, approximatel 1 and 2 miles respectively southeast of Blandon, and one at Five Points in the Birdsboro quadrangle. Three other very small areas are located in the Fleetwood and Temple quadrangles. Two exposures occur in the are near Blandon; elsewhere the mapping was based on float.

This rock was formerly termed the Furnace Creek quartz diorite gneiss by the writer (1953) after a locality on South Mountain in the Wom dorf quadrangle. This term is abandoned here, for the value of giving fo mal names to certain crystalline rocks of uncertain origin, age, and corre ation is rather doubtful. As discussed later, the quartz diorite gneiss appears to be a special sort of migmatite of variable composition, rather than a true igneous rock, and hence does not merit a formal name more than other migmatites of the Reading Hills. The current practice in cry talline rock areas tends to assign specific lithologic names rather than geographic formation names. These names give a better indication of th mineral composition of the rock, which is one of the chief factors in

correlation, and they also avoid a needless assemblage of formation names of uncertain value.

Petrography

Quartz diorite gneiss is a dark-greenish-gray to dark-gray rock with a grain size ranging from one-half to three millimeters. It bears some superficial resemblance to the common anorthosites of the Adirondacks. As it grades into hornblende gneiss it becomes very dark gray to nearly black. Quartz ranges from about 15 to 35 percent, andesine (An_{31-37}) from 58 to 74 percent, and hornblende about 15 percent. A little augite, hypersthene, biotite, garnet, and magnetite are present. Augite is usually fresh and relatively uncorroded, but hypersthene is much altered to a mixed aggregate, in part sericitic. Sericite contains potassium, hydroxyl, and aluminum ions which are not present in hypersthene, hence some introduction of these ions is necessary. The granitic material which helped form the quartz diorite gneiss as discussed below was probably the agent which brought in these ions. Some of the typical dark-colored gneiss contains over 10 percent potash feldspar, including both orthoclase and microcline, and hence should be termed a granodiorite. Some of it, indeed, grades imperceptibly into medium-gray granite.

The gneissic structure is less well-developed than that of hornblende gneiss, but is usually better defined than in granitic gneiss or the gabbroic gneiss variety of hornblende gneiss. In some places the gneissic structure is caused by the separation of bands of dark ferromagnesian minerals about one-sixteenth to one-eighth inch thick and one-quarter to three-eighths inch apart. The dark bands are not much over an inch long and not sharply defined, even though they are sometimes fairly conspicuous. The lighter bands between the darker ones contain greenish-gray quartz, plagioclase, and a little disseminated ferromagnesians. The light bands are very short and ill-defined, and the gneissic structure is caused by a slight elongation of quartz and feldspar and parallelism of hornblende, biotite, and some pyroxene.

Field Relations and Origin

All the small areas of quartz diorite gneiss grade imperceptibly into either granitic gneiss, hornblende gneiss, or into the common migmatites formed apparently by partial mechanical assimilation of hornblende gneiss by granitic gneiss. In some places quartz diorite itself contains diffuse bands and clots of hornblende and, or pyroxene, but usually it is homogeneous. At no place were sharp clear-cut contacts seen between quartz diorite gneiss and the associated hornblende gneiss and granitic gneiss, as might be expected if the quartz diorite gneiss represented a separate, distinct intrusive.

Quartz diorite is approximately intermediate mineralogically between granite gneiss and hornblende gneiss and appears to represent local masses of magma that had completely or almost completely assimilated hornblende gneiss. The nearly homogenous fluid magma then crystallized, but with a more basic bulk composition caused by the assimilation of hornblende gneiss. Turner and Verhoogen (1960, p. 360) refer to similar processes of which they state "The bulk composition of the contaminated granite tends to approach that of granodiorite or tonalite." In a sense the quartz diorite is thus only an unusual migmatitic variant of granitic gneiss, but its different mineralogy and field appearance justify mapping it separately. Somewhat similar processes are believed by Fraser (1941, p. 159-160) to have formed certain migmatitic gneisses in Lehigh County of composition intermediate between granite and diorite gneiss. As Park (1961, p. 31-38) has noted, certain quartz diorite bodies in the New Jersey highlands bear some resemblance mineralogically and texturally to the Reading Hills quartz diorite but as the field relations, particularly with granitic gneiss, do not appear the same, correlation is rendered difficult. Some of them appear to be separate intrusions not directly associated with granitic rocks as in the Reading Hills.

METADIABASE

Distribution and Occurrence

Metadiabase dikes are fairly numerous in the Reading 15-minute quadrangle, more occurring in the Fleetwood 7 1/2-minute quadrangle than the others. All but one are traced from the float. The only one that crops out trends east-northeast for about 2500 feet along the south end of Mt. Penn beginning near the conspicuous landmark, the Pagoda. The out crop is located a few feet from where the dike crosses the north-south road leading to Egelman Park. About 20 feet are exposed and the abundar float indicates the entire dike is about 50 feet thick. The top and bottom contacts with the crystallines are not exposed,so that the attitude of the dike cannot be directly determined, but a number of joints which may parallel the surface of the dike strike N52°E and dip 62°NW. This is nearly parallel to the attitude of the gneissic structure in the nearest crystalline outcrops 800 feet to the south. The only other large dike, located a mile north of Angstadt Hill in the Fleetwood quadrangle, trends northeast for about 3500 feet. It does not crop out but the abundant float suggests it is probably as thick as the one on Mt. Penn. The other dikes are much thinner and shorter and frequently are indicated only by a few pieces in the float. Most of them appear to strike to the northeast,though there are exceptions.

Petrography

Metadiabase is dark-greenish-gray to nearly black where fresh,

and weathers medium gray to brown. It is tough and resistant to weathering, in places forming float boulders locally known as "ironstone" which ring when struck with a hammer. The grains range in size from one-half to one millimeter. Diabasic texture, characterized by euhedral to subhedral plagioclase in a matrix of anhedral to subhedral pyroxene, is almost everywhere present. It is frequently visible in hand specimen if the rock is fresh. The main minerals include augite, about 25 to 40 percent; labradorite or andesine, 40 to 60 percent; and magnetite, 5 to 10 percent.

Augite is usually neutral to very pale brown. A few grains show twins with (100) as the twin plane. It is usually partly altered to greenish chlorite and some epidote. Orthopyroxene was not observed, but some of the diabase is so thoroughly altered that the residual pyroxene is very difficult to identify. In a review of some similar diabases near Henningsville in the Boyertown quadrangle, some pigeonite was found. It is neutral in color, positive, and has a 2V of about 40°. Green hornblende locally replaces augite, mostly along the edges of the crystals. Biotite usually occurs as a few, small, shred-like crystals. In one diabase it appears to replace hornblende, in another augite. It is altered in part to green chlorite. All the plagioclase ranges between andesine (An_{40}) and labradorite (An_{57}). Plagioclase is usually considerably sericitized and is altered frequently to a fine-grained, mixed, saussuritic aggregate. Magnetite exhibits a range of shapes from euhedral to anhedral. Rarely it shows skeletal crystals. Ilmenite, which occurs sparingly, is often indicated by leucoxene, which appears whitish in reflected light. Some of it occurs as band-like intergrowths in magnetite. Some hematite staining is usually present. Quartz, apatite, and pyrite are the accessory minerals. Quartz is found as minute anhedra and in rare micrographic intergrowths with feldspar. Apatite occurs frequently as elongate, nearly euhedral crystals; pyrite occurs as anhedral grains sometimes associated with magnetite.

Age

Two dikes, one 2 1/2 miles southwest of Lyons, the other 3/4 mile west of Oley Furnace are Precambrian, for they cut through the crystallines and abruptly end at the contact with the Lower Cambrian Hardyston Formation. These dikes, like similar ones in the Boyertown quadrangle, are rather strongly altered as described above. Presumably, most of the similarly altered dikes are also Precambrian. Near Henningsville, in the northern part of the Boyertown quadrangle, one petrographically similar dike was located (Buckwalter, 1956) which cut the Hardyston, and hence is at least post-Lower Cambrian. Its strong alteration, in contrast to the fresh Triassic diabases, precludes its being of this age. A poorly exposed dike of similar age and alteration may be present in the northeastern edge of the Fleetwood quadrangle, a mile south of Lyons. Though exposed only

in float, this dike appears to have been intruded along a small tear fault which offsets the Hardyston Formation. It has apparently intruded into the Hardyston for a few hundred feet along the fault.

PALEOZOIC ROCKS

HARDYSTON FORMATION

Distribution

The Hardyston Formation underlies much of all the longer, higher ridges of the quadrangle such as Mt. Penn, Deer Path Hill, Neversink Mountain, and Irish Mountain. Many of the narrow ridges of the Fleetwoo quadrangle are underlain almost entirely by this formation. The occurren of Hardyston as the dominant ridge maker is in marked contrast to its occurrence in Lehigh County adjoining to the east. In that area Miller (1941, p. 165) states: "A generalized statement with only a few minor exceptions is that Hardyston strata crop out in a narrow band on the comparatively steep slopes of the gneiss hills, generally near the base althoug in a few places extending to the crest of the hills." In a few places, however, in the Reading quadrangle Hardyston occurs in relatively flat, lowe tracts like the broad exposure south of Fleetwood.

Stratigraphy and Petrography

The lowest 25 feet of the Hardyston is apparently everywhere a light to dark gray, sometimes reddish-brown, coarse, quartz-pebble conglomerate. Because of intense folding, local thrusting, or cover, the lowest apparent beds at some exposures are not the true base of the formation and may not be conglomeratic. Actually at only one quarry in the entire quadrangle, on the west end of Sand (Wagoner) Hill, is the exact contact of the Precambrian crystallines, here granitic gneiss, and the Hardyston conglomerate exposed. At many places, however, the lowest conglomerate outcrop and the nearest crystalline float are only a few feet apart. The contact is also sometimes indicated by a slight topographic break where the slightly less resistant crystallines begin. The beds of the Hardyston are massive, ranging from about one to three feet thick. The size of the coarser fraction ranges from granules (2-4 mm.) to pebbl as large as 2.5 centimeters. The percentage of the coarser fraction vari from about 30 to 60 percent. The pebbles are almost entirely rounded to subrounded quartz, but pink and white feldspar may comprise as much as 20 percent of the granule and finer sizes. Some of the quartz pebbles exhibit very wavy extinction, suggesting a metamorphic source rock such a granite gneiss. The most abundant feldspar is microcline and microcline perthite, although orthoclase and pagioclase also occur. The finer fracti of the conglomerate ranges from very fine (1/16 mm.) to very coarse (2 mm.) in size, coarse to very coarse (1-2 mm.) being commonest. Fe

spar may constitute up to about 20 percent of this fraction. The ratio of the pebble and granule fraction to the finer fraction varies considerably, as abundant pebble zones may disappear laterally in a few tens of feet. In some places, vertical variation also occurs, as at Oley Furnace where beds of coarser conglomerate, 6 inches to 1 foot thick, alternate with beds of finer conglomerate, 6 inches to 9 inches thick. All the conglomerate contains an exceedingly fine matrix comprising from 1 to 15 percent of the rock and consisting usually of clay and occasionally of sericite, chlorite, or silt and clay-sized quartz and feldspar. Where the matrix is 15 percent, the rock may be termed a graywacke conglomerate. As accessory minerals, the conglomerate contains zircon, ilmenite partly altered to leucoxene, yellow-brown tourmaline, and apatite.

A plotting of the percentage of feldspar in the lower conglomerate from visual estimates in thin section and hand specimen, indicates that it increases slightly toward the northern and especially northeastern part of the quadrangle, suggesting the source area lies in that direction. In the southern part near Neversink Mountain and Mt. Penn, feldspar does not exceed 3 percent, to the north near Irish Mountain, it comprises 3 to 5 percent, and at Oley Furnace to the east it averages about 10 percent. The percentage of detrital silt-and clay-sized matrix is also higher toward the east. Grain sizes of the medium to coarser fractions, the framework, do not appear significantly different over the quadrangle with the present data.

At three localities, in a large quarry on the north face of Neversink Mountain, an old one on the south end of Mt. Penn, and one on the west end of Sand (Wagoner) Hill, a phyllitic rock occurs just below the base of the Hardyston conglomerate. This phyllite has been included (Miller, 1941 p. 171; 1944, p. 234; Stose and Jonas, 1935, p. 760) within the Hardyston Formation by some. This very fine-grained, dense phyllite is usually medium to dark gray or reddish gray and has a rather weak slaty cleavage. It is composed mostly of widely variable amounts of sericite and crushed quartz and potash feldspar. The Mt. Penn "pinite" is almost entirely sericite except for about 10 percent magnetite and 15 percent hematite, whereas that at Neversink is about 50 percent sericite and 50 percent crushed quartz and feldspar. Rocks similar to both the Mt. Penn and Neversink pinites may be found at Sand Hill. At both Mt. Penn and Neversink about 8 feet of pinite occurs directly below the conglomerate and is not in observable contact with the underlying crystallines. At Sand Hill, about a foot of pinite lies within a sheared granitic gneiss a few feet below the Hardystone contact. This occurrence within gneiss, as well as the granulated, sheared appearance and the presence of quartz, and feldspar, and sericite, all strongly suggest that "pinite" is a cataclastic product of granitic gneiss. The pinite was probably caused by intense shearing and is not a part of the Hardyston Formation. The slight recrystallization of the sheared gneiss to a sericitic phyllite, the elongation of

grains at several places in the conglomerate and common suturing of the conglomerate all indicate a low-grade regional metamorphism, in addition to simple cataclasis. The low-grade metamorphism was not intense enough to convert overlying carbonate rocks to marble.

Overlying the lower conglomerate, and imperceptibly grading into it, is an indefinitely bounded group of light-gray to reddish-gray, conglomeratic, frequently feldspathic quartzites, here termed the "transition" beds. The percentage of pebbles and granules is usually 10 to 15 percent, much less than in the conglomerates below. The matrix is a fine to coarse feldspathic sandstone, differing little from that of the overlying rocks described in the following paragraphs. This transitional group merges without obvious boundaries into the typical quartzite and feldspathic sandstones above. It varies from about 50 feet thick in the southern part of the quadrangle at Neversink Mountain to approximately 100 feet near Irish Mountain.

Most of the Hardyston above the transitional beds consists of fine-to-medium-grained, quartzose sandstone, sedimentary quartzite, and feldspathic sandstone. Light-gray, clean quartz-pebble conglomerates with a quartzose sandstone matrix are rare, but occasionally occur even high in the section. The sandstones are usually light gray, but white, light buff, dark gray, reddish gray and blue gray all occur. A very few exhibit thin bands a millimeter or so thick, apparently of very fine magnetite. The thickness varies from 6 inches to about 18 inches. Cross-bedding is rare, and was observed in abundance at only two localities, one a mile west of Alsace Manor in the Fleetwood quadrangle and the other on the first ridge south of Irish Mountain. Some of the quartzite has a vitreous luster, so that individual grains are hard to distinguish, but in others clay from weathered feldspars results in a slightly earthy appearance. A few of the quartzose sandstones are fairly friable and weather easily into loose sand. Feldspathic beds are common and, as Miller (1944, p. 234) has noted, have little stratigraphic significance. Feldspar comprises from 5 to 20 percent of these beds. They become slightly more abundant to the east and the feldspar content more commonly near 20 percent. In the Boyertown quadrangle to the east, feldspathic beds are considerably more abundant and contain up to 30 percent feldspar.

Under the microscope, quartz commonly shows marked undulatory extinction and is often elongated in secondary cleavage planes. It is rarely however, lineated also in the cleavage planes. Potash feldspars, both orthoclase and microcline, are more numerous than plagioclase. Feldspar is almost indistinguishable in hand specimen from quartz in some of the feldspathic quartzites, though readily apparent in thin section. It is sometimes indicated by its pink color or by chalky kaolinized grains. Sericite is occasionally present, especially along secondary cleavage planes. Zircon and tourmaline are the chief heavy detrital minerals. Worm tubes,

referred to as Scolithus linearis (Miller, 1944, p. 234) are found generally in the lower part of the section. As with the lower conglomerate, cataclastic and also low-grade regional metamorphism are indicated by crushed quartz grains, sutured contacts between the grains, elongation of grains to five or six times their width, and frequent development of slaty cleavage planes.

In the eastern part of the Reading Hills, in the Boyertown quadrangle and particularly in Lehigh County, jasper is locally abundant at the approximate contact of the Hardyston and overlying Tomstown carbonates. In the Reading quadrangle, jasper is almost negligible, as it is found only sparingly in the float at two places, one on the north side of Irish Mountain and the other at the northeast end of the first Hardyston ridge south of Furnace Ridge. It is dense, yellow-brown in color like limonite, into which it elsewhere grades, and some is fractured with the fractures filled with fine-grained quartz and chalcedony. It is usually easily distinguished from the typically dark chert of the overlying carbonate rocks, as Miller (1944, p. 235) has noted. Petrographic evidence given by Fraser (1937, p. 58) and applicable in the Reading quadrangle, strongly suggests that jasper has largely replaced Hardyston quartzite. Stose and Jonas (1935, p. 772) indicate that jasper has formed by silicification of limestone along the sole of the large Reading overthrust. As Miller noted (1944, p. 240) jasper is absent in many places, as it is in the Reading quadrangle, where the thrust comes to the surface. Its occurrence on Irish Mountain, indeed, is at one of the Hardyston areas that were not believed by Stose and Jonas to be part of the overthrust block.

Shale is stated by Miller (1941, p. 213) to occur near the top of the Hardyston in Lehigh County, but the occurrence he refers to is in an old, now inaccessible mine. During the construction of the northeast Extension of the Pennsylvania Turnpike, near Vera Cruz in Lehigh County, about 50 feet of rotten shaly beds of the upper part of the Hardyston were temporarily exposed. In the Reading quadrangle, the only shales observed are a very few thin beds a few inches thick interbedded with the highly deformed orthoquartzites along the Reading Railroad tracks along the south side of Neversink Mountain. These are apparently well up in the section stratigraphically. They frequently exhibit well-developed slaty cleavage planes.

Thickness

The thickest measured section, that on the first ridge south of Irish Mountain, including the estimated part to the Precambrian, totals about 250 feet, but it is evident from the float and topographic expression that much more of the formation lies above this section. Cross sections along several lines in the quadrangle suggest the thickness as obtained in well-exposed ridges like Mt. Penn is about 600 feet. The sections indicate

thickening and thinning of the folds, hence the estimate is made on those parts of the ridges that appear least deformed. This thickness compares with an estimated thickness by the writer (1962) of 600 feet on South Mountain in the Womelsdorf quadrangle adjoining to the west, 400 feet at Lobachville in the western part of the Boyertown quadrangle, 250 feet near Bechtesville in the eastern part of the Boyertown quadrangle (Buckwalter, 1959) and 200 feet in Lehigh County (Miller, 1941, p. 214).

Measured Sections

The measured sections below describe the lithology of the Hardyston from the lower conglomerate well into the quartzite of the upper part. The section at Neversink Mountain displays the lower part of the section, that at Mt. Penn is higher up, and that at the ridge south of Irish Mountain is probably highest. Exact correlation between the quarries is not possible because of lack of marker beds. The terms for sandstones are in keeping with the usage of Pettijohn (1957, p. 295).

Neversink Mountain section. -- Located in a quarry on north face of Neversink Mountain at elevation 820' along road leading to settlement at the top (300' east of 75°54' W. longitude and 4,000' south of 40°20' N. latitude). The top of the formation is not exposed. The lower conglomerate is exposed and some of the "pinite" below it, but the Precambrian crystallines are covered.

Hardyston Formation

Middle and upper sandstones and quartzites

Unit	Unit thickness	Cumulative thickness
1. Orthoquartzite, quartz granules 10%, coarse quartz grains 90%, clay in pore spaces, vitreous luster common, light-buff to nearly white. Beds 3 inches to 8 inches. About 10% of section consists of thin conglomeratic zones. Pebbles in conglomerates strongly elongated. Former feldspar probably indicated by clay. Locally glassy texture where no granules.	12' 6"	12' 6"
2. Orthoquartzite, slightly feldspathic, coarse to very coarse, poorly sorted, light-gray, hard, dense. Beds 4" to 18" thick.	22'	34' 6"
3. Orthoquartzite, slightly feldspathic,		

	Unit thickness	Cumulative thickness
coarse to very coarse, pinkish-gray. Beds about 15" thick.	7' 4"	41' 10"
"Transitional" beds		
4. Conglomeratic orthoquartzite, granules and pebbles of pink, gray, and colorless quartz 40%, coarse quartz, some smoky, nearly 60% slight amount of feldspar and clay. Resembles a graywacke in upper part of interval. Beds 17" to 24". Slaty cleavage present.	23' 10"	65' 8"
5. Conglomeratic orthoquartzite. Quartz pebbles and granules 15-20%, irregularly distributed. A few beds 3-6" thick are non-conglomeratic. Matrix a medium to coarse-grained quartzite. Medium gray, matrix lighter in color than unit 6.	27' 4"	93' 00"
Lower conglomerate		
6. Orthoquartzitic conglomerate. Pebbles 4 mm. to 2.5 cm. Pebbles and granules 50-60%. Matrix dark medium to coarse-grained quartzite. Bedding not well-defined, massive. Pebbles elongated and oriented horizontally.	7' 11"	100' 11"
"Pinite"		
7. Phyllite, very fine grained, greenish-black, buff weathering. A few chlorite flakes 2-3 mm. West end of quarry.	8'	108' 11"

Mt. Penn section. -- Located in a quarry on the west side of Mt. Penn elow the Pagoda at elevation about 760' (2500' east of 75° 55' W. longitude nd 3000' north of 40° 22' N. latitude). Base and top of formation not exosed.

lardyston Formation
Upper sandstones and quartzites

Unit	Unit thickness	Cumulative thickness
1. Feldspathic sandstone, locally quartzitic, feldspar 15-20%, mostly weathered to clay, fine-grained, a few quartz grains as large as 1 mm., light-gray. Feldspar grains angular to subangular, shape of quartz grains indeterminate because of vitreous luster. Beds 3" to 10" thick. Bed is part of a rib left in north end of quarry.	10' 9"	10' 9"
2. Feldspathic sandstone like above, but coarse-grained. Grains subrounded to rounded.	4' 6"	15' 3"
3. Feldspathic sandstone, locally conglomeratic, 10-15% feldspar altered to clay, granules 30%, coarse grains 70%, light- to medium-gray. Beds 3"-10". Contains an 8" conglomerate bed with many pebbles 5 mm. long, some 1.5 cm.	3' 11"	19' 2"
4. Arkosic sandstone, 20% bleached clayey feldspar, medium-grained, nearly white. Beds 3" to 10". Two 1" and 3" clay beds between sandstone beds.	15' 10"	35' 00"
5. Feldspathic sandstone, feldspar partly altered to clay, very coarse 5-20% in various parts of interval, medium 80-95%. Massive beds, 4" to 2'. Nearly white. Well-indurated.	15' 1"	50' 1"
6. Feldspathic sandstone, like unit 5, but medium-grained.	20' 00"	70' 1"
7. Orthoquartzite, slightly feldspathic, very coarse 3-5%, coarse 20%, medium 75%, light- to medium-gray and buff. Beds 6"-18". Fucoid-like features on two bedding planes. Some coarse-grained pink quartz.	8'	78' 1"
8. Feldspathic sandstone, 5-10% feldspar partly weathered to clay, very coarse		

	Unit thickness	Cumulative thickness
5%, coarse 15-20%, medium 75%. Weathers nearly white on bedding planes. Beds 2"-1'. Near top of interval numerous Arthrophycus-like forms.	16' 3"	94' 4"
"Transitional" beds		
9. Orthoquartzite, 5% feldspar, slightly conglomeratic, very coarse to granules 10%, coarse 30%, medium 60%, light-gray, rounded grains, moderately indurated.	13' 10"	108' 2"
10. Orthoquartzite like unit 9, but without granules.	3' 9"	111' 11"
11. Orthoquartzite, 5% feldspar, slightly conglomeratic, very coarse to granules 10%, coarse 30%, medium 60%, light-gray . A few zones are all medium, moderately indurated.	17' 7"	129' 6"
12. Covered. Estimated from dip of slope, dip of beds, lithology of float and distance to float of crystallines that about 80' of section including the lower conglomerate is present between the base of unit 11 and the Precambrian crystallines.		

Frush Valley road section. -- Located in a quarry on the south side of the first Hardyston ridge south of Irish Mountain. Accessible from and a few hundred feet west of Frush Valley road. Elevation is about 600'. Located 200' south of 40°25' N. and 240' east of 75° 54' W. The base and top of the formation are not exposed.

Hardyston Formation
Middle and upper sandstones and orthoquartzites

Unit	Unit thickness	Cumulative thickness
1. Partly covered. Interval contains two broken, slumped groups of beds, each 10' thick similar to unit 2, except for		

	Unit thickness	Cumulative thickness
prominent cross-bedding.	76'	76'
2. Orthoquartzite, slightly feldspathic, feldspar about 5%, 5% medium grained, 95% fine to very fine, very light gray. Films of clay present. A few thin zones consisting mostly of quartz granules. Well-indurated.	7'	83'
3. Orthoquartzite, slightly feldspathic, 1-2% feldspar, 10% granules, 10% very coarse grained, about 80% fine to very fine-grained, light gray. Larger grains subrounded to subangular. Moderately indurated.	8'	91'
4. Covered.	5'	96'
5. Orthoquartzite, fine to very fine-grained, light gray. A few clay films on surfaces. Slaty cleavage present. Moderately indurated.	4'	100'
6. Covered.	4'	104'
7. Orthoquartzite, coarse-grained 10-15%, fine-grained 85-90%, very light-gray. Slaty cleavage present. Well-indurated.	12'	116'
8. Covered.	5'	121'
9. Orthoquartzite, slightly feldspathic, less than 5% feldspar, 20% coarse-grained, very light-gray. Slaty cleavage fairly conspicuous. Some clay present on joint and bedding faces. Well-indurated.	6'	127'
10. Nearly all covered. Float similar to unit 7.	25'	152'
11. Orthoquartzite, slightly feldspathic, less than 5% feldspar, mostly fine-grained, a few grains as large as 1/2 mm.,		

	Unit thickness	Cumulative thickness
very light-gray to white. Beds 4"-6". Feldspars partly altered to clay. Rough, white-weathering bedding surfaces. Slaty cleavage ill-defined. Well-indurated.	16'	168'
12. Covered. Float like unit 5.	15'	183'
13. Orthoquartzite, very similar to unit 5.	8' 7"	191' 7"
14. Fault zone. Weathers as a depression in face of quarry wall. No outcrops within zone. Almost entirely covered.	11'	202' 7"
Transitional beds		
15. Conglomeratic, slightly feldspathic orthoquartzite, feldspar 5-10%, coarse-grained to granule sizes, 15%, although in a few lenses these sizes comprise up to 30%. Some beds very low in coarser fraction. Matrix medium to coarse, pinkish where fresh, weathers nearly white due to formation of clay from feldspars. Larger grains subrounded. Beds 10" to 1'. Vitreous luster in much of interval.	80' 10"	283' 7"
16. Covered. Precambrian crystallines estimated to be 65-75' below base of unit 9.		

CAMBRO-ORDOVICIAN CARBONATE ROCKS

Cambrian-Ordovician carbonate rocks are the subject of a separate study by the Pennsylvania Geological Survey, and hence not directly within the scope of this report. They are poorly exposed within and adjacent to the crystallines and the Hardyston Formation except near Neversink Mountain. There a number of outcrops of the Leithsville Formation (Tomstown) are exposed, especially in the Reading Railroad cuts southwest of Neversink Mountain and in some sharp small anticlines between Neversink Mountain and the village of St. Lawrence (Esterly). The formation at these localities is mostly a cream-colored dolomite to dolomitic limestone with beds about 4 to 18 inches thick. In places, as along the Neversink Mountain cuts, it is finely laminated. At St. Lawrence, six inches of shale is interbedded with massive dark-gray dolomite. Along the Lancaster

pike, U.S. 222, a mile southwest of Shillington, the dolomite is also slightly shaly. Here, upon weathering, some thin layers of the carbonate stand out in relief due to lesser solubility.

The contact of the Leithsville and Hardyston is everywhere cover ed. It is usually picked along Hardyston ridges at the beginning of the firs steep slopes if no other evidence is available. In some broad flat valleys within the crystalline and Hardyston hills, such as that in which Stony Creek Mills is situated, or the one immediately west of Deer Path Hill, carbonate rocks do not crop out at all. They are inferred by the low, nearly flat topography, suggestions of karst topography, chert nodules, or local reports of hard water in wells.

The Martinsburg Shale, which underlies much of the Great Valle occurs sparingly in float in two places in the area studied; one at the edge of the Reading Hills east of Frush Valley in the Temple quadrangle, and the other near Oley (Friedensburg)at the west edge of Oley Valley in the Fleetwood quadrangle. It is a light-gray to brown, fissile, non-calcareou shale with conspicuous slaty cleavage. Minute crenulations occur in som of the cleavage planes. Sericite appears to have developed in the cleavag planes, to judge from inspection of hand specimens.

At Frush Valley the Martinsburg is overlain by a thrust block of gra itic gneiss which has been granulated near the contact to an augen gneiss. Ne Oley it is also in contact with crystallines, probably occurring in the wes sheared limb of the major synclinorium presumably underlying Oley Valle

STRUCTURE

PRECAMBRIAN STRUCTURE

In the quadrangle 69 outcrops were found on which the strike and dip of the foliation and, rarely, the lineation could be measured. This includes 40 in the Fleetwood quadrangle, 21 in Birdsboro, 2 in Temple, and 6 in the Reading quadrangle. The readings from these outcrops serv to give a general picture of the Precambrian structure, but details are largely lacking except at Antietam Reservoir in the Birdsboro quadrangle where outcrops are numerous. With few exceptions the foliation strikes northeast in the southern part of the hills west of Oley Valley and east to northeast in the northern part in the Temple and Fleetwood quadrangles. The dip is generally to the southeast. However, in a few areas where the outcrops are close together, like Angstadt Hill or a mile south of Blandon, some of the gneisses dip to the northwest and it is apparent the structure does not everywhere conform to the simple southeast regional dip that widely spaced outcrops suggest.

To a considerable extent the foliation of the metasediments, in

cluding here hornblende gneiss, parallels that of granitic gneiss, especially at Antietam Lake where both are well exposed. Similar relations have been noted in northern New Jersey (Sims, 1958; Hague, 1956) and the suggestion made that the granite was intruded as concordant sheets or phacoliths into the metasediments. An alternative explanation is that much of granitic gneiss is "granitized" metasediment as outlined in the section on the origin of granitic gneiss. Parallelism of foliation of granitic gneiss and metasediments would thus be expected.

The configuration of hornblende gneiss areas on the whole conforms fairly well to the regional northeast to east trend. Two conspicuous exceptions occur on the east side of Mt. Penn where roughly horseshoe-shaped broad bands have been traced in the float. These may indicate large plunging folds, but no outcrops are exposed to substantiate this interpretation.

PALEOZOIC STRUCTURE

Overthrust Interpretation

The outstanding Paleozoic structure is the major uplift which has exposed the Precambrian crystallines and lowest Paleozoic rocks which form the bulk of the Reading Hills. This major structure comprises the easternmost part of the Reading Prong, which continues eastward across southeastern Pennsylvania, into northern New Jersey, southeastern New York, and western New England. The structural interpretation of the Reading Hills part of this uplift has been the subject of controversy for many years. In 1935, Stose and Jonas proposed the hypothesis that the crystallines and associated lower Paleozoics constitute a great sheet which has been thrust over the Cambro-Ordovician carbonates and shales of the Great Valley. Several lines of evidence were presented, of which the most important were stratigraphic and structural discordances between the beds of the overthrust sheet and adjacent overridden ones, windows in the thrust sheet, zones of mylonite, the presence of detached masses of the overthrust sheet, and indications that jasper had formed in the carbonate rocks where overridden by the thrust plate. All of these points were strongly contested in papers by Miller or Fraser (Miller, 1936, 1944; Fraser, 1938, 1939, 1941) who presented, particularly in 1944, a great mass of detailed evidence, some of it relating to the Reading quadrangle. Some of this evidence which applies particularly to the Reading quadrangle and which has been reviewed by the writer is noted below as well as some data which has become available recently.

Stratigraphic and also structural discordances are cited by Stose and Jonas at several places in the quadrangle, notably near Frush Valley, Bernhart Hill, Jacksonwald, the west and south sides of Mt. Penn, and the west edge of Oley Valley. Beyond question, immediately south of Irish

Mountain, at Frush Valley, Bernhart Hill, the south side of Mount Penn, at the core of Dengler Hill, the west side of Carsonia Park Valley, and along most of the edge of the Reading Hills from St. Lawrence east to Oley Valley and thence along almost the entire edge of Oley Valley into the Boyertown quadrangle, crystalline rocks are in discordant contact with Cambro-Ordovician carbonate rocks or shales. These discordances were known from earlier mapping and were explained by Miller (1944) by a combination of normal faults and local thrusts. According to his interpretation, almost all the crystallines and Hardyston, except that along local thrusts, is in place. The discordance along the west side of Mt. Penn and Deer Path Hill indicated on Stose and Jonas' maps by Hardyston beds in contact with Elbrook and Conococheague carbonates rather than the Tomstown dolomitic limestone which normally overlies the Hardyston, is not demonstrable. No carbonate formations were found at all by the writer or earlier by Miller on the west slopes of Mt. Penn or the adjacent valley or in the valley between Deer Path Hill and Bernhart Hill. Inquiry among local residents gave no indication that limestone has either cropped out or been quarried in the area for many years.

Recently the U. S. Geological Survey (Bromery and others, 1960) has flown much of southeastern Pennsylvania with an air-borne magnetometer and has published magnetic maps for all of the quadrangles in this area. In areas where the crystallines are in place, considerable magnetic relief is to be expected; where, however, the crystallines are relatively thin as in a thrust plate overlying carbonate rocks, the magnetic intensity would be little if any greater than that in areas of carbonate rocks. Examination of the magnetic data of the four 7 1/2-minute quadrangles of this area strongly suggests that most of the crystallines are in place, but that locally they are not and are presumably overthrust. Thus on Neversink Mountain, despite the presence of exposed crystallines occurring 600 feet above the surrounding level, the magnetic intensities are little higher than over the carbonates of the Great Valley and no higher than those over the carbonates between Mt. Penn and Neversink. Likewise at Bernhart Hill, the magnetic intensity is about 25 gammas lower than in the carbonate valley immediately to the east. However, the entire exposed mass of Precambrian and Hardyston on this hill is small and probably would not exhibit much magnetic intensity even if rooted in place. At Frush Valley the magnetic intensity builds up fairly rapidly east of the Martinsburg-Precambrian contact, suggesting that the thrust there is of small horizontal displacement or may be only a reverse fault. In other areas of crystalline which are in contact with carbonate rocks, the magnetic intensities are enough higher in the crystalline areas as compared to the adjacent carbonates that it is probable the crystallines are rooted in place. The discordant contacts are apparently then caused by some other type of structure than a major overthrust, possibly normal faults as suggested by Miller or, it seems to the writer, sheared out folds which are discussed below.

At a number of places within the Reading Hills, intermontane alleys with nearly flat bottoms floored with carbonate rocks are found. ome penetrate into the hills from the south border like the one in which tony Creek Mills and Carsonia Park in the Birdsboro quadrangle is ocated, or the large Oley Valley which occupies many square miles in the eading and Boyertown quadrangles. Other smaller ones, like Dale Valley n the Boyertown quadrangle or the one reported to be at Antietam Cove, a ile south of Alsace Manor in the Fleetwood quadrangle, are completely nclosed by the crystalline rocks of the hills. Most of them are bordered n one or more sides by the Hardyston Formation. These valleys were elieved by Stose and Jonas to be the floor over which the thrust plate was ushed, now exposed by erosion of windows in the thrust block. Miller aintained that they were formed largely by down faulting and by folding f the sediments into deep synclines. He presented a wealth of field detail which there is little new to add. The writer believes these windows are rgely strongly sheared synclines of the type explained in the discussion f the Hardyston ridges.

In the Stony Creek Mills valley, Stose and Jonas indicated the mestone floor to be Elbrook which would be in discordant contact with the ardyston Formation which dips northwesterly into the valley on its east order. The writer found no outcrops of limestone in this valley. Without efinite evidence to the contrary, it would be presumed the carbonate would e the Leithsville (Tomstown) which normally overlies the Hardyston. The agnetic maps of Reading and Fleetwood quadrangles indicate an area of w magnetic intensity in this valley as would be expected in an area under- in by carbonate rocks. It should be noted that while all the carbonate eas are areas of lower magnetic intensity, all areas of low magnetic tensity are not underlain by carbonate rocks. Two conspicuous "lows" outh of Pricetown and north of Oley Furnace in the Fleetwood quadrangle e underlain by crystalline rocks.

Antietam Cove, a mile south of Alsace Manor, is indicated by ose and Jonas to be an irregular low, partly swampy area underlain by e Elbrook carbonates. The flat area is small and confined to the imme- ate valley of Antietam Creek southwest of Chapel (Capella) Hill. Miller und no evidence of carbonate rocks, but located some Hardyston float at e southeast edge of the cove across the road from the Alsace Township hool. Except for a very minor amount of Hardyston float found along exico Road directly north of Chapel Hill, the writer found no indication sediments. Float of hornblende gneiss and granitic gneiss is abundant. ith the present data the lithology of the underlying rocks here is indeter- inate, but the float indications suggest that the rocks consist of crystallines d possibly a very minor amount of Hardyston. Two areas of low magne- intensity occur in the cove, one southwest and one north of Chapel Hill. th continue into areas of undoubted crystalline rocks and are of about e same magnitude as lows elsewhere in the crystalline rocks. Wilkens

(1957, p. 98) has noted that similar valleys in the crystallines occur elsewhere in the Reading Hills.

As noted in the section on the Hardyston Formation, reddish- to yellowish-brown jasper is occasionally found in the Reading Hills at the approximate contact of the Hardyston Formation and the overlying Leithsville (Tomstown) carbonates. It is believed by Stose and Jonas to be a replacement of limestone along the sole of the overthrust plate. Fraser (1937) showed that some jasper is formed by replacement of Hardyston quartzite. Thin sections cut by the writer permit the same interpretation As Miller (1944, p. 236) states, chert of the limestones is usually readily distinguished from the jasper at the Hardyston-Leithsville contact. As he also notes, (p. 237), if jasper is formed along the thrust plane, it might occur along the long edges of the thrust on the west side of Mt. Penn, or on the east side of the hills adjacent to Oley Valley, but none was found by the writer in these areas. Jasper is very sparse in the Reading quadrangle. Miller also notes that the occurrences of jasper do not often appear to be along the traces of the overthrust, as some are too high, and in some extensive areas, as in the Reading quadrangle, it is absent where it might be expected.

Zones of mylonite have been cited by Stose and Jonas to have bee formed along the sole of the thrust. Miller and Fraser (1936, p. 2035) stated that such zones were much more extensive than required by the location of the traces of the overthrust. The writer has found a very sheared, nearly mylonitic zone east of Breezy Corners in the Fleetwood quadrangle in a position well above the presumed thrust. It is more in line with the shear zones which seem to typify the prominent Hardyston ridges of the quadrangle. Mylonite was also found in granitic gneiss abou 3000 feet east of the large quarry on the north end of Schwarzwald Hill and well above the base of the thrust. In any event, mylonitic zones need not necessarily indicate the sole of thrusts, but may be developed in areas of intense shearing or faulting.

Hardyston Ridges

A structural problem of interest and wide application throughout the quadrangle is that relating to the structure of the long narrow Hardyston ridges which are numerous, particularly in the Fleetwood and Temp quadrangles. This subject was discussed by the writer in an earlier pape (1960), some parts of which are utilized below. Five of these ridges located between Walnuttown and Alsace Manor in the Fleetwood quadrangle (Fig. 3) are fairly well exposed and are shown in the sections illustrated.

Figure 4 is a section through the ridges without any attempt at interpretation. Except for the northernmost ridge all dip to the south an

re overturned. In all the basal conglomerate is exposed on the south ide of the ridge. The evidence for the overturning is two-fold. The chief vidence is that the basal conglomerate is seemingly overlain by gneiss. : is essential in any interpretation to be certain the conglomerates are ctually basal and not some occurring higher in the section. In only one f the six sections measured in the Reading quadrangle does any conglom- rate occur above the base, and this, in the section on Mt. Penn, is a lean quartz-pebble conglomerate hardly to be mistaken for the typical ather dirty, dark, feldspathic conglomerate found at the base. At all laces where the conglomerate occurs, even in float, the Precambrian rystalline rocks are usually only a few feet away. The second evidence f overturning is the gentle dip of slaty cleavage. In an abandoned quarry n the north end of the Hardyston ridge which terminates near Breezy orners, the slaty cleavage dips about 30° south whereas the beds dip bout 45° south. Less well-developed cleavage occurs on Sand (Wagoner) ill and also on the ridge immediately north of Alsace Manor.

An interpretation of this outcrop pattern which is readily con- eived is that of a series of imbricate thrusts, which have broken over- rned folds, each block being thrust to the north (Fig. 5). The direction thrusting is thought to be toward the north because nearly all the struc- res in this part of the Appalachians are asymmetric to the north or rthwest. After the thrusting had occurred, the blocks would be piled higher to the south, hence some southward tilting would be necessary restore them to a horizontal position. This relatively simple thrust terpretation does not fit the outcrop pattern, because the normally dip- ng limbs of each anticline should be present, yet no trace of them exists.

A somewhat similar thrust interpretation (Fig. 6) fits the outcrop ttern better. In this interpretation, the thrust blocks are alternate in mber and include alternately the overturned limbs and the normally pping limbs. The normal limbs, not present at the surface, are thrust ward with greater displacements than the overturned limbs, which lag hind. Although there is some resemblance to horst and graben structure al the blocks are thrusts, with the overturned ones lagging behind. A rious objection to this interpretation is that it is too coincidental that cly the normal blocks are upthrust and the overturned ones lag behind. his might happen occasionally, but four times out of four is rather im- obable. The interpretation also requires that the fold break at the ests and troughs of the folds rather than the limbs where they would esumably be thinnest. Finally, the location of the thrust planes on the rth side of the overturned lagging blocks must be just right, for if they ae too far north, the overlying limestone would be exposed, and if too f south, some or all of the overturned limb would be cut out.

A much different interpretation is shown by Figure 7 which il- trates the development of a series of overturned fault blocks with little

or no folding. In the earliest stage north-dipping fault planes bound the fault blocks (Fig. 7, section 1); in the later stages (sections 4, 5) these fault blocks are overturned to the north. The earlier faults are presumably gravity faults with little displacement (section 1), those of intermediate stages thrust faults (sections 2, 3, 4) and in the last stage (section 5) they are again gravity faults. Use of wooden or paper models of this system shows conclusively that the latter stages are technically gravity faults, even though some compressive stress still is operative from the south. The chief objection to this interpretation is that the observed slaty cleavage is not adequately accounted for, since little or no folding has occurred. Rotation of fault blocks does not appear to be a suitable method for the formation of slaty cleavage. The Hardyston beds are here moving as large units within the fault blocks, rather than differentially and intergranularly as they do in folds. Thus, known methods of forming slaty cleavage, such as rotation of grains, crystallization of platy minerals, crystal gliding, or elongation of existing minerals, do not seem applicable. If slaty cleavage tended to form at roughly right angles to stress, it would constantly be rotated out of position. Also rotation of the blocks to the degree required would almost certainly necessitate very considerable brecciation along the fault planes. Such wholesale brecciation is not obvious in the field, but this may be because the rocks near the presumed faults are poorly exposed. Another objection to this interpretation is that early gravity faulting is probably not to be expected before strong compression starts. The late gravity faulting seems almost inevitable as manipulation of models suggests. This interpretation also does not satisfactorily explain the apparent variations in thickness of the Hardyston at the different ridges, a variation more readily explained by folding. Still another objection is that this rather elaborate mechanism seems unlikely to occur for a single isolated overturned ridge like some of the others in the Reading Hills.

Overturning of the beds by folding, followed by gravity faulting (Fig. 8) is a simple mechanism which can result in the actual outcrop pattern. After faulting, the southerly blocks would necessarily be at a lower elevation than the northerly ones, hence northward tilting is necessary to get the row of folds approximately on a horizontal plane as they appear to be now. This interpretation lacks some of the complexity of the thrusting version shown in Figure 6 and readily accounts for the slaty cleavage, unlike the overturned fault blocks of Figure 7. However, as in the thrust interpretation of Figure 6, the faults must be spaced at just the proper place in the folds, somewhat of a coincidence for four successive folds. Some coincidence cannot be considered a fatal objection to any of the interpretations, for the structural pattern is uncommon and some uncommon mechanism must cause it. The northward tilting essential to this version makes a third step necessary to achieve the present configuration. In general, it is probably safe to say, as a variant of William of Occam's razor, that the more complex the structural mechanism used

explain a given effect, the less probable it is, if a simpler mechanism available.

The final version presented here is shown by Figure 9, a series overturned folds in which the north limb, the normal one, is sheared . Here again some coincidence occurs in that four folds in a row are s sheared. Slaty cleavage and variations in thickness are readily ex-ined by this method. Very strong folding and shearing in the Hardyston, newhat as indicated by this version, occurs in numerous outcrops on south side of Neversink Mountain along the Reading Railroad, about miles south of this area. Elsewhere it is not very evident, although re are indications on Irish Mountain just west of this area, on South untain near Wernersville, and on the ridge south of Shillington. In st outcrops of Hardyston an insufficient area is exposed to see how nplex the folding really might be. A point in favor of this interpretation the simplicity of the mechanism, for no other movement is required er than very strong folding. This simplicity seems rather appealing some of the other overturned Hardyston ridges in the Reading quad-gle, like Spies Hill, which are more isolated than the series discussed e. For single ridges a complex set of structural operations seems re improbable than where several ridges are involved.

An objection that may be raised to this version is that it is dif-lt to perceive why only the north normal limbs of the synclines are ared out and not the overturned ones to the south or indeed both. First, south limbs have thinned somewhat as can be seen by comparing the kness of the Hardyston near Walnuttown with that at Alsace Manor. ondly, the particular outcrop pattern shown here, which seems to re-re shearing out of only the north limbs, is commonest in the Reading ls, but not unique. Thus, on the large Hardyston hill just north of ep Hill and west of Angstadt Hill in the Fleetwood quadrangle, the urrence of Hardyston conglomerate float only on the north side of the suggests that the south limb of the syncline should be sheared out. he large limestone "window" at Dale in the Boyertown quadrangle ch is surrounded by crystallines, no Hardyston at all is present along at of the north and south borders of the valley. Presumably the Hardy-n here is sheared out on both the north and south limbs.

Another objection that may be raised is that the Hardyston is too tle and competent to flow as required by this version. The Hardyston rittle and competent at the surface now, but when it was folded at eth, as on Neversink Mountain, it must have been semi-plastic to judge he intricacy of the folds (Figure 13) and the local shearing and thinning.

The interpretation of sheared folds indicates that the Hardyston olded to a depth of about 3000 feet below the surface, and also that since axial planes dip to the southeast, much of it is buried south of the exposures.

Some indication that the folding extends deeply is afforded by the magnet pattern. The Hardyston has a lower magnetic susceptibility, about .01 x 10^{-3}emu/cc, compared to that of the crystalline rocks which have a range of .02 x 10^{-3} to 5.20 x 10^{-3}emu/cc. They might then be expected to show a magnetic low if they occur in substantial volume near the surface in a crystalline area.

Almost all the numerous Hardyston areas in the Fleetwood quadrangle are associated with some type of magnetic low, usually in the same location as the Hardyston body or a short distance to the south. The correlation of the size and shape of the ridges and of the magnetic features is far from consistent, however. Two magnetic lows, one east of Boyers Junction and the other at Sand Hill, both coincide closely in shape and size with the Hardyston exposures. Elongate lows are located slightly south of most of the Furnace Hill Hardyston ridge and also that at Alsace Manor. The group of broad exposures of Hardyston, extending from Fleetwood almost to Pricetown, is indicated magnetically by an equally broad area of low magnetic relief. Most of the line of ridges which form the northern boundary of the hills lie in irregularly shaped, generally east-west trending magnetic lows or in areas of low magnetic relief with an intensity only 50 to 100 gammas higher than that of the Great Valley. However the Hardyston ridge east of Alsace Manor extends from an oval-shaped low onto the edge of a small high and that at Breezy Corner lies on the edge of a high.

In the Birdsboro quadrangle, Guldin Hill and Schwarzwald Hill are both indicated by areas of low magnetic relief and intensity. In the Reading quadrangle the Hardyston areas of Mt. Penn and Deer Path Hill extend from the low magnetic area of the Great Valley carbonates onto the west edge of large magnetic highs which underlie the crystalline rocks. As mentioned above, Neversink Mountain and the ridge south of Shillington show low magnetic relief and intensity. The relation of magnetic pattern and Hardyston exposures is similar in the Temple quadrangle to that in the Fleetwood quadrangle, as two ridges largely coincide with lows and one with a high. Irish Mountain, with an exposed crystalline core and ridges of lower conglomerate and "transition" beds near its center is marked by a large area of high magnetic values. It seems probable in the four quadrangles that at least some of the "grain" of northeast to east-trending lows is related to similarly trending exposures of Hardyston. In a few areas, particularly east of Sand Hill, the elongate magnetic lows extend beyond the exposed Hardyston ridges, suggesting that the synclinal fold of the ridge is pinched out at the surface on both limbs, but is present at depth.

As the great bulk of the hills are underlain by gneiss which strikes roughly parallel to the trend of the magnetic features, it would seem probable that some variations, perhaps lithologic, might affect the

rain" of the magnetic configurations. These variations are not obvious om surface exposures, however, as highs and lows both occur in areas c granite and seem to bear little relation to other rock types like horn- ende gneiss which might be expected to give higher magnetic readings cause of their higher magnetic susceptibilities.

A variation of the sheared syncline hypothesis that would eliminate e difficulty of shearing only one limb and not the other is one in which ly the basal conglomerate is sheared out on the north limb and both mbs undergo thinning. It is almost as difficult, however, to explain why e conglomerate should shear out on one limb and not the other, as to plain why one whole limb is sheared out and not the other. The basal nglomerate contains more detrital matrix than the quartzites and sand- nes above. This matrix does recrystallize into sericite and chlorite slaty cleavage planes as can be observed at Breezy Corners, the west d of Sand Hill, or in the Hardyston ridge east of Alsace Manor. It is ssible the presence of these platy minerals in abundance may permit re shearing and flowage parallel to the slaty cleavage planes than in quartzites above, and ultimately result in shearing out of the conglom- ate.

The writer would like to make clear that he does not regard the sion illustrated by Figure 9 as the final answer to the problem. At sent, it seems to explain the observed field relations more simply n the other interpretations presented above, but it evidently has serious rtcomings. The writer would welcome comment on these hypotheses l particularly suggestions of alternate hypotheses that would more sat- actorily explain the observed field relations.

Neversink Mountain

The largest and most numerous exposures of the Hardyston in cks County are those on Neversink Mountain, particularly along the ading Railroad tracks on the west and south sides. There many rela- ely small folds are exposed in considerable detail. The results of mination of all outcrops is shown on the accompanying three maps ch indicate the bearing and plunge of the fold axes (Fig. 10),the strike dip of axial planes (Fig. 11), and the strike and dip of the limbs of ds (Fig. 12). A sketch is also given of the main outcrops along the thern end of the large horseshoe curve of the railroad along the south e of the mountain (Fig. 13). The line of the sketch is thus curved and view of the outcrops is always toward the north.

The fold on the north central side of the mountain is not com- ely exposed but is of considerably larger magnitude than nearly all folds by the tracks on the south side. Some of the latter have wave gths of only a few feet and would not be recognizable except in good

exposures. Almost all are asymmetric, many are isoclinal and overturned. All the fold axes strike between approximately 35° north of west and 45° south of west . Most of them are within 20° north and 30° south of west. Of 51 axes, 46 plunge to the northwest or southwest at angles varying between 0° and 30°. The other five plunge to the southwest or northeast at angles varying between 6° and 16°. All the 47 reliable readings of axial planes strike between N40° E through N90° E to N40° W with 23 striking nearly east-west. All but 7 dip to the south with a wide range of 14° to 80°. The 7 northward dipping axial planes are all steep, ranging from 50° to 90°. A few axial planes are indicated by slaty cleavage or by conspicuous shear planes. Most were directly observable. Many of the folds are overturned as indicated on the map showing strikes and dips of the limbs of folds. Where possible,these readings were taken on fairly persistent broad bedding planes,but on small folds the dip even on the limbs changes rapidly. Faults on Neversink include the inferred trace of the thrust plane, referred to above, two conspicuous small steep faults on the northwest side and a few too small to map. The Precambrian core on the north side must be bordered by faults on at least the west end, for the belt of lower conglomerate exposed on both sides of the core is abruptly terminated by the crystallines.

If Neversink Mountain were in place, the strike and dip of axial planes and the overturning of numerous north limbs of anticlines and south limbs of synclines would indicate the force causing folding came from the south. However, as noted above, Neversink is apparently a large thrust block and may have undergone some rotation during thrusting. Its orientation with its long axis at 70° to solidly rooted Mt. Penn, only half a mile north, strongly suggests it has undergone angular as well as horizontal displacement. The strong resemblance of the Hardyston beds and the crystallines, poorly exposed as they are, to those in the hills to the north suggests that Neversink has not been thrust a great distance.

It is of interest to consider why the tight, intricate, relatively small folds so typical of the south and west side of Neversink are apparently rare in the rest of the Reading Hills, except for the similarly overthrust Hardyston ridge south of Shillington on South Mountain near Wernersville, and on Irish Mountain. Such structures are apparently not common even on the north side of Neversink though few exposures are present. This rarity may be more apparent than real for few good, large exposures are found elsewhere. Nonetheless the few large areas where sections have been measured, such as on Mt. Penn, Schwarzwald Hill, or Furnace Hill, indicate larger scale folds with few if any minor complex folded structures. The lithology of the beds is similar, the only noteworthy differences being the presence of a few very thin shaly beds at Neversink and a tendency for the quartzitic beds to be thinner. One hypothesis is that Neversink and the ridges to the southwest may have been thrust some miles from an area where deformation was more intense or at least of a

ferent type. This seems improbable, however, for in the adjoining eat Valley, structures of great complexity, including nappes, have en located recently (Gray and others, 1958; Geyer and others, 1958), d as mentioned above, the lithology of the beds on Neversink is similar that of the rest of the Reading Hills.

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